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Surface Layer Stability Transition Research Maximum Time Delay from Sunrise/Non-Ideal Conditions: 2001 June Case Study

by Gail-Tirrell Vaucher and Manny Bustillos

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Preface

In 2001, the U.S. Army Research Laboratory, Meteorological-sensors Integration Team, conducted a series of three field tests in the southwestern desert of the United States. The purpose was to identify, characterize, and exploit repeatable atmospheric patterns found in the lowest layer of the Boundary Layer, the Surface Layer. The repeatable pattern selected was the Surface Layer Stability Transition. Each field test was timed with the purpose of validating a seasonal extreme in the annual morning Stability Transition (ST) timing cycle. The seasonal minima, equated with the Equinox months, are documented in separate technical reports. This technical report focuses on the seasonal maximum point occurring in the Solstice month of June.

Each field test serves as a building block in the overall goal of modeling the ST. The information gained from these field tests has three fundamental links to the U. S. Army and to the military in general:

1. This research expands on U.S. Army Chief of Staff Shinseki's vision.
2. The knowledge of exploitable atmospheric characteristics, such as an ST, enhances electro-optical weapon effectiveness and efficiency.
3. The accurate ST forecasts provide crucial initializing information for atmospheric models that forecast chemical and biological weapon effects, as well as transport and diffusion effects.

Acknowledgements

Appreciation is extended to the Meteorological-sensors Integration Team (MIT) members for their successful execution of the 2001 June Atmospheric Surface Layer Field Test. The MIT Team members included: Robert Brown, Edward Creegan, Doyle "Scott" Elliott, Alfred Gutierrez, David Quintis, Gail Vaucher (Team Leader) and Jimmy Yarbrough. Also, appreciation goes to Ms. Nancy Fudge, for her efforts in linking the remote site field test activities with the demands of the standard work hour routines.

Executive Summary

U.S. Army Chief of Staff Shinseki stated that his U.S. Army vision was to see first, act first, and kill first. In GovExec.com's *Daily Briefing*, Freedberg Jr. wrote that the most powerful, accurate and quickest weapon on the planet is the laser. Both military concerns have one major hurdle, "seeing" through the atmosphere. The Surface Layer Stability Transition (SLST) Research has been investigating naturally occurring atmospheric patterns that enhance or detract from the successful "seeing" mission. These same Stability Transition (ST) patterns also provide knowledge of when the effects of chemical and biological weapons will shift from foe (toxic concentrations in a limited area) to friendly (non-toxic concentrations in a broad area), and vice versa. Likewise, initializing the convective Boundary Layer growth phase (ST) impacts civilian and military Atmospheric Dispersion/Diffusion Model accuracy. For the military, knowing when a smoke screen will "clear", for example, could prove to be a significant strategic advantage on a battlefield.

In 2001, the Meteorological-sensors Integration Team conducted three field tests with the primary purpose of characterizing, modeling, and exploiting repeatable patterns in the lower portion of the Atmospheric Boundary Layer. The repeatable patterns investigated were the morning ST, or Neutral Events (NE). The 2001 June 20–22 dates were selected based on a forecasted maximum time interval between the local Sunrise and an Ideal ST case. Two other correlated field tests address the seasonal sunrise-to-NE time interval minima (March, September, 2001). These latter tests are documented separately.

The SLST research pursued two measurement and analysis methods: Eulerian (Tower data) and quasi-Lagrangian (Rawinsonde data). The June 2001 results unexpectedly provided a healthy dataset for Non-ideal ST conditions. Within these three days were excellent examples of a pre-dawn NE, extended NEs, and multiple NEs. The information documented here serves as a useful building block in support of their primary purpose.

1. Introduction

This publication is the second of three technical reports documenting the 2001 Surface Layer ST Field Tests. Sections 1.1 and 1.2 are reproduced from the *Surface Layer Stability Transition Research, Minimum Time Delay from Sunrise: 2001 March Case Study* (Vaucher et al., 2003).

1.1 U.S. Army Interest in Atmospheric Stability Transition Research

Atmospheric Stability Transition (ST) Research links to military interests in at least three arenas. In the July 2002 *Army Materiel Command Newsletter*, U.S. Army Chief of Staff Shinseki stated that his vision for the U.S. Army was "to see first, act first, kill first…To see first, we must have persistent and pervasive intelligence-gathering capabilities" (Burlas, 2002). The atmosphere is one of the major hurdles retarding the efficiency of "seeing first." The Boundary Layer Exploitation Task-Surface Layer Stability Transition (SLST) Research has been investigating naturally occurring atmospheric patterns that enhance or detract from the successful "seeing first" capability. Under favorable atmospheric conditions, target identification is potentially done quicker, making the last two actions of the Shinseki's U.S. Army vision more efficient and effective.

Sydney Freedberg Jr. wrote in his GovExec.com *Daily Briefing*, that the most powerful, most accurate and quickest weapon on the planet, the laser, has one major obstacle, the weather (Freedberg, 2001). To quantify the atmospheric impact on this, or any other electro-optical (EO) weapon, one needs to understand a parameter called "seeing". To an astronomer, "seeing" is the arc second or angle occupied by the star image at the full-width and half-maximum of its intensity profile, as viewed from a specific point in the atmosphere (Businger et al., 2002). "Seeing" improves or degrades with changes in the atmospheric optical turbulence strength and location as quantified by profiles of the refractive index structure function C_n^2. The SLST Research grew out of EO propagation research, and now serves as a building block for understanding and forecasting the naturally occurring atmospheric cycles that are both favorable and non-favorable for the laser and any subset of this weapon type.

Finally, a significant urban warfare hazard is the release of chemical and biological weapons. The atmosphere, specifically the Boundary Layer convection, can enhance or detract from the weapon's effectiveness. From a military perspective, knowledge of a ST means knowledge of when the chemical and biological weapon's effect will shift from foe (toxic concentrations in a limited area) to friendly (non-toxic concentrations in a broad area), and vice versa (Angevine et al., 2001).

Likewise, initializing the convective Boundary Layer growth phase (the ST) is a primary interest to civilian and military Convective Boundary Layer and Atmospheric Dispersion/Diffusion

Modelers. Model results often reflect the initial input accuracy. For the military, knowing when a smoke screen will "clear", for example, could prove to be a significant strategic advantage on a battlefield. Thus, the ST pattern ties to both military and civilian applications (Angevine et al., 2001). Additional civilian interests will be described in the next section.

1.2 Civilian Interest in Atmospheric Stability Transition Research

The Atmospheric Boundary Layer behavior during the period between the fully developed convection of mid-day and the stable conditions of the nocturnal Boundary Layer is poorly understood, but is of interest in several fields, including chemical and pollutant modeling (Grimsdell and Angevine, 2002). Grimsdell and Angevine focused their work on the afternoon ST in agricultural environments. However, their assessment regarding the poor understanding is also true for the morning Surface Layer ST in a desert environment.

Finally, in the June 2002 *Bulletin of the American Meteorological Society*, Businger et al., describe the unique weather forecasting requirements for the highly technical stellar viewing at Hawaii's Mauna Kea Observatories. Clear air turbulence in both the free atmosphere and in the Boundary Layer were flagged as causes for image distortion and blurring for their ground-based telescopes. Forecasting the observing quality for seeing parameters accurately is a key factor in the successful scheduling of these very expensive civilian optical and infrared instruments. Knowing when the atmospheric impact would be minimal, such as during a ST, would be a significant improvement and enhancement for the astronomical community (Businger et al., 2002).

1.3 Purpose and Overview

The purpose of this report is to document the results and new understanding gleaned from the 2001 June Solstice-Atmospheric Surface Layer Field Test*,* conducted by the U.S. Army Research Laboratory (ARL), Meteorological-sensors Integration Team (MIT). This test was executed at Thompson Tower (Lat: 32.35, Long: -106.47), White Sands Missile Range (WSMR), NM. The overriding mission of this second of three fiscal year 2001 (FY01) field tests, was to validate the proposed Seasonal Algorithm used in forecasting the exact time of the morning ST. This goal stemmed from a larger Atmospheric Boundary Layer investigation: to characterize and exploit the repeatable patterns found within the lower portion of the desert Atmospheric Boundary Layer (Surface Layer). A routine mechanism for describing the Surface Layer is turbulence (Tatarski, 1961). Turbulence directly impacts the stability of the Surface Layer, which in turn affects the U.S. Army's ability to function efficiently. Thus, the research results feed both the scientific goals of better understanding the Atmospheric Boundary Layer dynamics, and the U.S. Army's need to improve their efficiency while working in the Surface Layer.

1.4 Background of the Stability Transition Study

The following historical review of the ST study is reproduced from the Surface Layer Stability Transition Research, Minimum Time Delay from Sunrise: 2001 March Case Study (Vaucher et al., 2003).

The initial ST study was funded by the Atmospheric Science Laboratory and conducted at the U.S. Army-owned High Energy Laser Systems Test Facility (HELSTF), NM in the mid-1990s (USASL Contract). This study was prompted by an operational need to minimize the impact of atmospheric optical turbulence (AOT) on the High Energy Laser (HEL) when propagating along a 1 km path. Based on observations, the HELSTF meteorologists noted that twice a day the AOT would drop to a minimum. These AOT minima correlated closely with the morning and evening STs.

Over time, ARL meteorological operational researchers developed a “rule of thumb” approach for forecasting the morning and evening STs. This “rule of thumb” suggested that a minimum amount of AOT occurred when the atmosphere was neither stable, nor unstable, and that such a “Neutral Event (NE)” occurred 60 min after sunrise, and 40 min before sunset. While the “rule of thumb” was able to yield a ballpark accuracy, the high cost of HEL testing quickly demanded a more precise forecast. Thus, a more rigorous investigation began.

In 1994, Vaucher and Endlich published results from the first of two significant studies. According to their 2-month study, the average occurrence of the morning NE was about 70 min after sunrise. The time difference between sunrise and the associated NE ranged between 40 and 133 min after sunrise. The evening NE occurred an average of about 60 min before sunset, with a Sunset-NE time difference ranging between 98 and 12 min before sunset (Vaucher and Endlich, 1994). They also noted that there was an implied trend in their statistical findings. Consequently, a follow-on study was pursued.

In 1995, Vaucher and Endlich published the results from a 16-month AOT NE study conducted at HELSTF, NM. Recognizing the local heat flux as the primary contributor to AOT, the authors isolated three variables (Sunrise/Sunset time, Delta-T and Insolation) related to the heat flux, and observed their relationship to the NE over a 1 km desert path. The 16 m minus 2 m Temperature (T) difference (Delta-T) was examined at the start and end of the sampling path. Results reported near-surface, slightly dry adiabatic conditions present during a NE. The NE-insolation values showed that the ranges of insolation magnitudes at the Sunrise-NE were about twice those sampled at the Sunset-NE. This observation was explained as a function of the sun’s elevation.

The most significant discovery of the 1995 study, with respect to ST forecasting, came while overlaying local sunrise and NE times. The minimum average time difference between local sunrise and NE was reported in the Equinox months. The maximum monthly time difference average occurred in the Solstice months. Vaucher and Endlich theorized that the skewed diurnal heating-cooling cycle of the solstice periods generated strong near-surface temperature inversions that delayed the transition into the near-dry adiabatic atmosphere required for a NE. During the Equinox, the 24-h heating-cooling cycle was nearly equal. Therefore, minimal time was needed for the day or nighttime atmosphere to transition into the near-dry adiabatic environment (Vaucher and Endlich, 1995).

Figure 1 displays the seasonal effect discovered by Vaucher and Endlich. In this figure, the Sunrise NE (SRNE) Rule of Thumb Forecast is contrasted with the actually observed NE time.

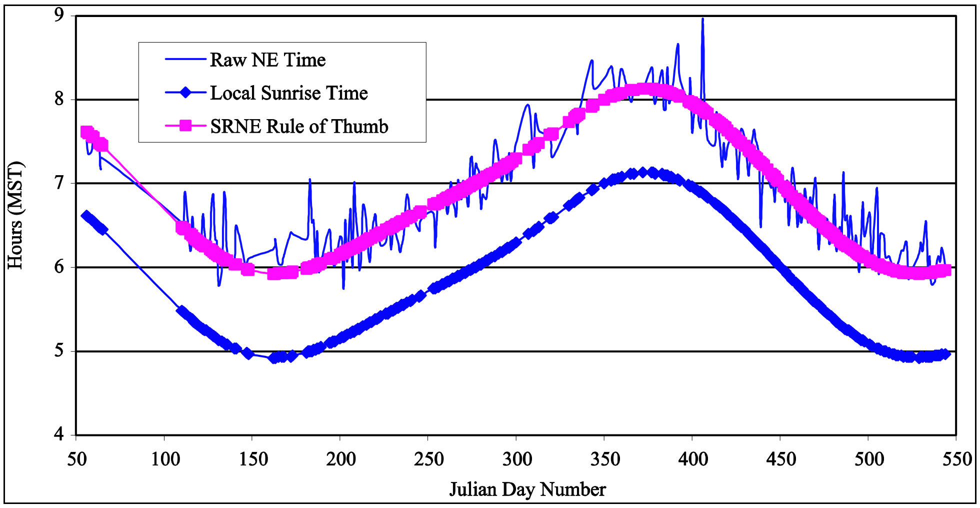

Figure 1. Local Sunrise, SRNE Rule of Thumb, and NE Times, 1994 February-1995 June (Raw Data).

To display the oscillation more plainly, figure 2 shows the "rule of thumb", the monthly averaged NE time, and the actual NEs.

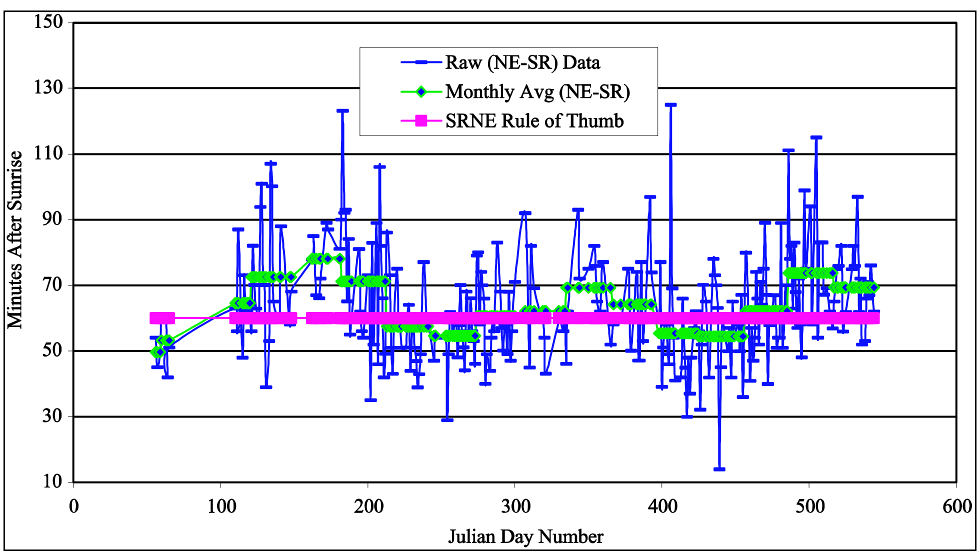

Figure 2. SRNE Rule of Thumb, Raw and Monthly Averaged NEs, 1994 February-1995 June.

Removing the actual data, figure 3 shows the annual cycle of average NE by month. Note he Equinox NE minima (September, March) and the Solstice NE maxima (June, December). The first minimum is ignored due to the lack of data for the initial month.

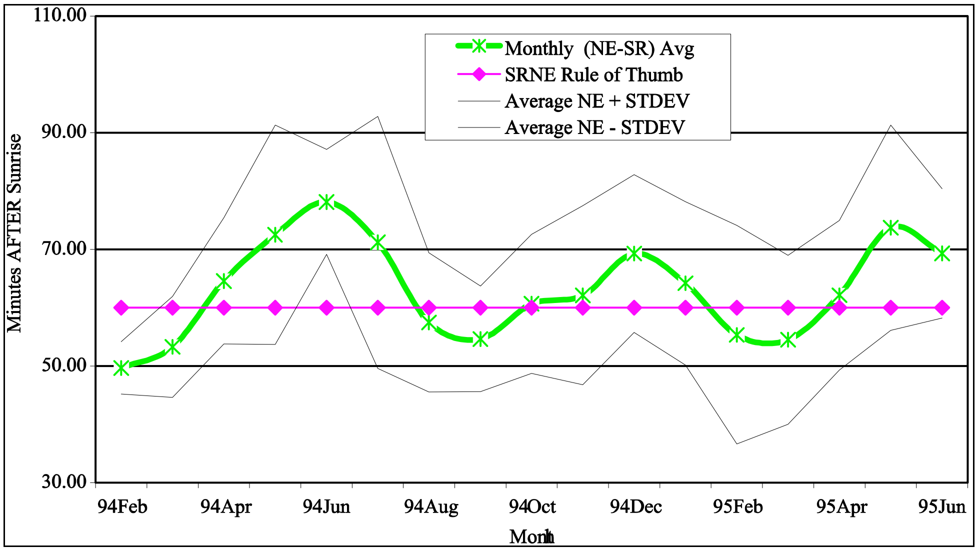

Figure 3. Monthly Averaged Sunrise Neutral Event Time Differences, 1994 April-1995 June.

Based on the 16-month study, Vaucher and Endlich updated the Rule of Thumb NE Forecast approach by introducing a seasonal correction curve. The coefficients produced by the Fourier Waveform Analysis can be found in their 1995 Battlefield Atmospheric Conference paper (Vaucher and Endlich, 1995).

The 16-month study left some unanswered questions:

1. Are the updated Rule of Thumb NE Forecast algorithms site specific? What about a non-desert environment? What about other latitudes?

2. Is the seasonal oscillation real or a coincidence?

3. The current model works under Ideal atmospheric conditions. What about under Non-ideal conditions (see section 1.6)?

ARL addressed some of these questions during the FY01 field tests. First, however, this report examines the ST character and the Ideal versus Non-ideal atmospheric conditions.

1.5 Character of the Stability Transition

The ST character is best understood by examining a full 24-h stability cycle. Figure 4 presents a "typical" diurnal (a March Equinox AOT time series over a high elevation desert site in the southwestern United States) and can be used as a visualization tool for the following stability cycle description. Additional information on typical stability cycles can be found in *Meteorology for Scientists and Engineers* (Stull, 2000) and *An Introduction to Boundary Layer Meteorology* (Stull, 2001).

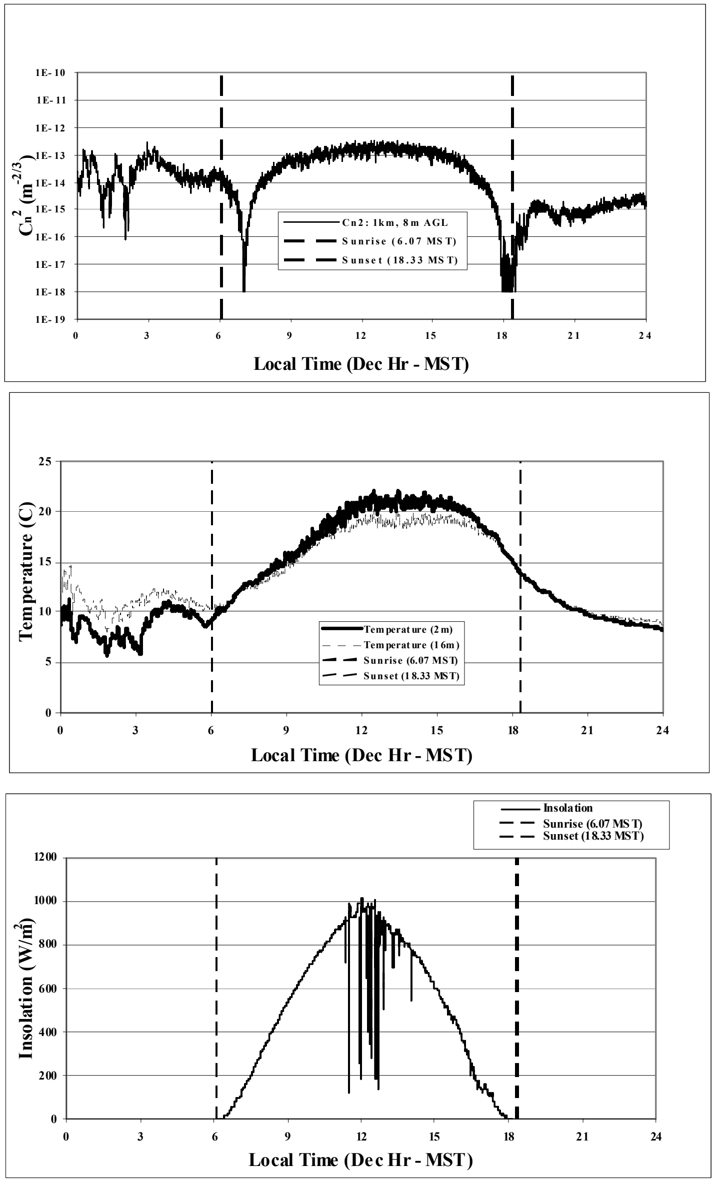

Figure 4. Coincident C_n^2, Temperatures, and Insolation Time Series along a 1–km path for 24 March 2001 at HELSTF, NM.

0000-Sunrise. Under clear skies, calm winds, and low ground moisture, the desert basin at 0000 hours Local Time is stably stratified. The coldest temperatures are at the lowest levels (Delta-T > 0). The heat flux is negative, and the AOT is a moderate-to-low level. Katabatic flow off neighboring mountains serves as a catalyst for overturning and mixing the nighttime stable atmospheric layers. The result is a mélange of density variations, which produces intermittent maxima of AOT. If winds decrease, AOT will return to the normal moderate-to-low level.

Sunrise occurs. The rays of sunrise start warming the ground, which radiates heat into the lowest atmospheric layer. The heat flux steadily increases, causing the stable atmosphere to become isothermal and "neutral." C_n^2, coincidently, drops to a minimum. This is the morning, or Sunrise AOT NE.

Daytime. As the sun continues warming the ground throughout the morning, the neutral stability shifts into an unstable state. The heat flux is positive. The vertical temperature differences are now negative and C_n^2 increases. Atmospheric convection attempts to rebalance the unstable conditions by mixing the near surface warm air into the cooler air aloft. The persistent sun strengthens the unstable state, deepening the mixed layer. The constant mixing intensifies the atmospheric density variations and the AOT further increases. AOT reaches a peak around midday, or soon after.

The waning of the sun in the clear afternoon skies reduces the insolation and decreases the negative Delta-T magnitudes. Subsequently, AOT decreases. Just prior to sunset, the atmosphere briefly becomes near-dry adiabatic (neutral) and C_n^2 drops to a minimum. The heat flux goes to zero and the day's second NE takes place.

Sunset occurs. Civil, Military and Astronomical Twilights quickly evolve until there is the nighttime darkness. The previously warmed soil strongly emits the Solar Radiation absorbed during the daylight hours and cools rapidly. Delta-T becomes positive, confirming the presence of a stable atmosphere. Colder, heavier air, from the surrounding mountains and hills, drains into the valleys, serving as a mixing tool. The non-uniform radiative cooling and clear sky drainage flow creates an ambient mixing, which keeps the AOT at a moderate level throughout the night. The moderate AOT is punctuated by occasional, intermittent AOT maxima.

Within the diurnal cycle just described, the two primary NE times are clearly linked with the local sunrise and sunset. As the stable nighttime conditions transition to unstable daytime conditions, a Sunrise NE occurs. Likewise, as the unstable daytime evolves to a stable nighttime atmosphere, a Sunset NE occurs. Common to both scenarios is a period in which the atmosphere is near-dry adiabatic, exhibiting the least variations of C_n^2 along a horizontal and vertical path. The target of the SLST research is to successfully forecast the initial time for these transition events (Vaucher et al., 2003).

1.6 Ideal and Non-ideal Stability Transition Forecast Standards

Two distinct scenarios, Ideal and Non-ideal atmospheric conditions, were observed during the mid-1990 ST studies:

1. Ideal atmospheric conditions were defined as clear skies, low winds and low ground moisture.

2. Non-ideal atmospheric conditions included all other atmospheric traits, especially any cloud occultation of the sun during sunrise/sunset.

Local atmospheric conditions determined the ST duration. Under Ideal conditions, the transition was often less than 2 min. Ironically, the Ideal condition ST forecast (with seasonal correction algorithms) produced the best results for the HELSTF, WSMR, NM site. In fact, one could accurately forecast to the minute when a Sunrise NE would occur 9 months in advance of the forecast, presuming that the day of validation had Ideal atmospheric conditions.

Forecasting for the Non-ideal atmospheric scenario was another story. First, the NE duration was anywhere from 1 min to over 20 min. In this technical report, the 2001 June Solstice-Atmospheric Surface Layer Test data will show an atmospheric transition state being sustained for at least 26 min. Another characteristic of Non-ideal scenarios was the generation of multiple NEs. Some major contributors to these Non-ideal NE conditions included:

1. Solar disc occultation during sunrise/sunset.
2. Sun ray obscuration after sunrise/before sunset.
3. The presence of local ground moisture.
4. The presence of non-standard local forcing (such as a frontal passage).

2. Seasonal Algorithm Statistical Maximum Test

In section 1.4, "Background of the Stability Transition Study," figure 3 showed the statistical maximum in the seasonal algorithm to be in the Solstice month of June. Climatologically, June in New Mexico is hot, dry, and dominated by clear skies. The probability for accomplishing our desired objective was high.

2.1 2001 June Solstice-Atmospheric Surface Layer Test Overview

The 2001 June Solstice-Atmospheric Surface Layer Test was executed in two phases: a Pre-Test was conducted 5–7 and 19 June; and the actual Test occurred 20–22 June. The test site used was the 100 ft Thompson Tower site at WSMR, NM, with a scintillometer path extending about 1 km west-southwest to the Ammo Site. Participants of the Test included the members of the MIT, Dave Tofsted of ARL's Weather Exploitation Branch and Carlos Marrerro (a visiting student). The Test Coordinator was Gail Vaucher. The purposes of the Test, with their point-of-contacts (POC), were:

1. To be the second of three FY01 sampling sets aimed at verifying the maximum and minimum magnitudes of the Neutral Event Forecasting Model seasonal effects (POC: Gail Vaucher).
2. To quantitatively characterize the desert Atmospheric Surface Layer by studying the atmospheric lapse rate changes (stability), wind currents, and insolation during the night-to-day transition period (POC: Doyle "Scott" Elliott).
3. To characterize atmospheric transition events aloft via the Wind Profiling Radar (POC: Edward Creegan).

Prior to the field test execution, two 4 m scintillometer towers (Thompson Tower and Ammo Site) were re-leveled and secured for use, and cabling was repaired (local wildlife had damaged existing cables). The temporary housing for the computer equipment at the remote Ammo Site was provided by a Commercial Utility Cargo Vehicle with shelter. The power for the site was a mobile 20 kW generator. A mobile High Speed Trailer (HST) attached to hard power provided the equivalent for the Thompson Tower site. The versatile HST served as a Post-test data processing center and Testers' Conference Room.

Meteorological sensors included a 4 m TacMet II Unit at Ammo Site, and two surface sensor units linked by a Campbell Data Logger at Thompson Tower. Sensors on Thompson Tower were mounted at 2 m, 5 m, 38 m, and 39 m levels. Vaisala global positioning system (GPS) rawinsondes were launched from a High Mobility Multi-Wheeled Vehicle (HMMWV) situated west of Thompson Tower. The HMMWV also served as the housing for the 924 MHz Wind Profiling Radar. The Wind Profiling Radar Antenna was placed west of Thompson Tower and slightly southwest of the HMMWV. A 25 kW Quiet Generator powered the HMMWV. The HST was placed north and slightly west of Thompson Tower. A Field Test Structures and Sensors Layout diagram was documented in the Test Logbook.

During the Pre-Test check of equipment and acquisition capabilities, the tower meteorological sensors, radar, RAOB and scintillometer systems ran simultaneously. Errors were noted and solutions ultimately found for the RAOB and Radar systems. Scintillometer alignment was successful. The scintillometer software was in an experimental testing mode; therefore, the Pre-Test C_n^2 results were inconclusive. The rest of the Thompson Tower and Ammo Site Pre-test data were deemed acceptable.

2.2 Test Execution

Test Days 1–3 (2001 June 20–22) began at 0400 Mountain Daylight Time (MDT), with all participants traveling to the 100 ft Thompson Tower in a caravan. This strategy served to minimize desert dust around the field site. There were three data acquisition Sub-cases scheduled per day. These Sub-cases characterized the nighttime desert atmosphere (0430–0700 MDT), the onsite atmospheric NE (0700–0900 MDT), and the daytime desert atmosphere (0900–1100 MDT). A morning WSMR mission forced Test Day 2, Sub-cases 2 and 3 RAOBs to originate from a WSMR C-station RAOB launch location. All other RAOB launches were conducted at the Thompson Tower site; all Sub-case runs were uninterrupted.

2.3 Test Summary

This section begins with a brief characterization of the nighttime (stable), transition (NE), and daytime (unstable) Sub-cases. Section 2.3.2 describes the unique features of the three NEs observed during the June Test. The information presented in that section is based on the plots generated during execution of the Test. Additional details will be discussed in section 3 (Vaucher, 2001).

2.3.1 Characterization of Nighttime, Transition, Daytime Atmospheric Conditions

This section presents data from Days 1 and 2 only. Day 3 was excluded due to the complicating factors of a backdoor front stimulating some relatively rare, early morning thunderstorm activity east of the site. Day 3, the final test day, will be addressed later in this study.

General Synoptic Weather Information. An atypical (seasonally early) monsoon-type pattern over WSMR brought in a southeast flow of tropical moisture from the Gulf of Mexico. The abnormally high daytime dewpoint temperatures gave the area nearly an inch of Precipitable Water, resulting in the constant threat of afternoon thunderstorms (Forecast for White Sands Missile Range, Intellicast.com, Real-Time Weather Data, 2001).

Nighttime (0430–0700 MDT). Pressure (P) increased slightly (about +1 mb/Sub-case time duration) as the dawn hours approached. Cool temperatures were sampled near the surface, generating a Delta-T of +3 to +6 ^{o}C. Relative Humidity (RH) was significantly greater at 2 m than at 38 m. Winds were less than 5 m/s, with generally divergent magnitudes between the 5 m and 39 m sampling heights. Consequently, wind directions (WD) were also divergent, though often from the same gross northern quadrants. All test days reported clouds obscuring the stars, mainly along the eastern horizon.

Transition (0700–0900 MDT). The P continued to increase with time (about +0.7 mb/Sub-case time). Delta-T began with a stable +3 ^{o}C ($T_{2m} < T_{38m}$). After the transition/NE, Delta-T was approximately 2 ^{o}C (unstable). The greatest Delta-T rate of change was observed between 0724 and 0815 MDT. The RH began with a difference of 20% (greatest RH at 2 m). Then, like T, RH also transitioned, so that the greatest RH was at the higher level. The post-transition RH difference was less than 5% (dryer conditions generally at 2 m). Wind speeds (WS) between the 5 m and 39 m levels were less than 5 m/s. While the two levels began as pseudo-independent airflow, the magnitudes appeared to converge at the time of transition. This unified condition persisted throughout the end of this case. Solar Radiation (SR) showed the greatest rate of increase over this time period. Evidence of intermittent cloud cover was validated with the independently sampled observations that are in the Test Logbook.

Daytime (0900–1100 MDT). The smallest P change occurred during this Sub-case time period (–0.20 and +0.01 mb/Sub-case time). The Delta-T consistently hovered around –2 ^{o}C (unstable), with the warmest T at 2 m. The RH differences (2 m and 38 m) were less than 5%. The WS was < 5 m/s, with both tower levels reporting a relatively unified direction. The SR showed a slower rate of increase. Cloud obscuration was less over this time period.

2.3.2 Unique Neutral Events

All 3 days began with partly cloudy skies that evolved into isolated thunderstorms by evening. This pseudo-monsoon pattern consistently delayed the local sunrise. The UNOBSTRUCTED sunrise for this latitude and these dates would have been 0559 MDT (Day 1) and 0600 MDT (Days 2 and 3).

Day 1(20 June). Cirrus clouds delayed sunrise 6 min. Between sunrise and NE, there were two periods in which cirrus clouds fully obscured the sun. The consequences of the irregular surface heating manifested in a 27-min delay from the Ideal Conditions-NE Forecast time. The morning transition was a single event for this Test Day.

Day 2(21 June). Sunrise was delayed 9 min due to mid-level clouds along the eastern horizon (residue of early morning cumulonimbus). Intermittent occulting of the rising sun was coupled with the effects of a significant increase in local ground moisture from the overnight thunderstorms. The resulting delay in the Ideal Conditions-NE was about 49 min. The morning transition was a single event for Test Day 2.

Day 3(22 June). Day 3 presented the most fascinating data of the Test. This data set began in a nighttime NE. Without a calibrated scintillometer or imager to instantaneously validate the NE, the NE definition had to be subdivided into two empirically derived Delta-T threshold gradients: +/–0.25 and +/–0.09. Using the grosser threshold, the length of the in-progress NE was 26 min. The finer thresholds sampled a 4-min NE. One proposed explanation for the nighttime-NE was that the cool outflow of a local, active thunderstorm generated the extended, pre-dawn NE conditions.

Sunrise for Day 3 was delayed 31 min by the decaying anvil (cumulonimbus) occulting the solar disc. The abundance of cloud cover prohibited the normal steady increase in surface heating, resulting in three daylight-NE/STs. Using gross thresholds, these lasted 4, 10, and 3 minutes. Strangely, the first 4-min transition status overlapped the NE time forecasted for Ideal conditions. The final transition occurred once the solar disc had cleared the thickest of the altocumulus cloud cover. The time of the final transition was approximately 61 min after the Ideal NE forecast time.

3. Discussion of Results

Test Day 3 provided the most unusual results and is elaborated in this section. Previous observations have identified at least two unique NE characteristics under Non-ideal atmospheric conditions: Extended and Multiple STs. At the time of publication, the authors were not aware of any study that had documented the variety of ST durations. Since Extended and Multiple NE conditions present favorable opportunities to military interests, knowing the duration of these opportunities (even if approximately) becomes important. Understanding the prompting for these conditions is an interest of the academic community, since these observations further characterize the Surface Layer dynamics.

3.1 Extended Stability Transitions

Extended STs are normally associated with overcast, windy days. In contrast, the first extended NE of this test began at night. The very first Thompson Tower data sampled (0421 MDT) from Day 3 abruptly informed us that neutral conditions were already in progress. The 0435 MDT meteorological observations described the sky as "0.5 cirrus, no twilight visible, CB and lightning observed to the northeast" (Test Logbook, 2001). Surface winds were about 3 m/s from the north-northeast. Twenty-six minutes into our data acquisition, the nighttime NE silently eased into the more typical stable Surface Layer status. By 0450 MDT, the local Surface Layer observations reported "0.3 thin cirrus, less than 0.1 altocumulus, twilight on the eastern horizon and no lightning" (Test Logbook, 2001). These cloud conditions persisted for the next half hour with only the pre-dawn light increasing. As mentioned earlier, empirical analysis has tagged the non-threatening outflow of the active thunderstorm northeast of the Test Site as being the catalyst for this unexpected atmospheric condition.

Observations at local sunrise (0600 MDT) stated that the solar disc was obscured by cirrus, pink clouds (altocumulus/cirrus) to the south, no stars were visible, only a planet was visible, and an anti-twilight arc was beginning to form. Within 15 min, the planet was no longer visible. The sunrays were slipping through random slits in the cloud deck, illuminating the very tops of the western mountain peaks. Not until 0631 MDT did the solar disc finally clear the horizon clouds. Surface winds were less than 5 m/s and had shifted to the south, southeastern quadrants. Unfortunately, the sun's unobstructed path did not persist.

3.2 Multiple Stability Transitions

On Test Day 3, the first of the multiple STs occurred within the Ideal NE forecasted time (0711 MDT) plus/minus one standard deviation. No observations were taken at the start of the extended post-dawn NE (0708–0711 MDT). However, the 0710 MDT observation reported "0.3 AC, 0.1 cirrus, sun blocked by thick AC" (Test Logbook, 2001). The local atmosphere briefly returned to a stable state before the next NE.

The second of the three transitions (0716–0725 MDT) was also an extended NE. No significant atmospheric changes were observed from the initial transition. Clouds continued to occult the sun. Following this 10-min event, the local atmosphere, again, returned to the stable condition. Altocumulus cloud cover increased over the subsequent 42 min.

By the last of the multiple transitions (0812–0814 MDT), observations were "0.9 AC, 0.1 cirrus with clearing to the south" (Test Logbook, 2001). Surface winds were around 3.7 m/s out of the south. A healthy, persistent daytime unstable atmosphere followed this last NE.

4. Conclusion

Expect the unexpected. The atmospheric conditions anticipated for this June Test were clear skies, high desert temperatures, and very dry. In other words, Ideal conditions for validating the NE Forecasting Model. The actual Test's atmosphere was a 2-week, early monsoon pattern: cloudy skies, moderately high temperatures, moist ground, early morning thunderstorms, and even the threat of a gust-nado sighted to our west. While this atypical weather pattern challenged the ongoing validation of the NE Forecasting Model, it also provided excellent evidence (documentation) of nighttime NEs, extended NEs, and the occurrence of multiple daytime NEs. The mission of this second of three field tests was to identify, characterize, model, and exploit repeatable patterns within the Atmospheric Surface Layer that are useful to the military. After reviewing the results of the Test, it is the authors' opinion that this Test gained an unexpected significance in that it provided quantitative evidence that even under "bad" or Non-ideal weather conditions, the atmospheric surface layer has exploitable military value (i.e., NEs) for those who have the eyes to see this benefit.

Acronyms

AGL	Above Ground Level
AOT	Atmospheric Optical Turbulence
ARL	U.S. Army Research Laboratory
C_n^2	Index of Refraction Structure Function
Delta-T	Temperature Difference [$T_{38m} - T_{2m}$]
ELR	Environmental Lapse Rate
EO	Electro-Optical
GPS	Global Positioning System
HEL	High Energy Laser
HELSTF	High Energy Laser Systems Test Facility
HMMWV	High Mobility Multi-wheeled Vehicle
HST	High Speed Trailer
MIT	Meteorological-sensors Integration Team
MDT	Mountain Daylight Time
NE	Neutral Event
P	Pressure
POC	Point of Contact
RAOB	Rawinsonde Observation System
RH	Relative Humidity
SLST	Surface Layer Stability Transition
SR	Solar Radiation
SRNE	Sunrise Neutral Event
ST	Stability Transition
T	Temperature
WS	Wind Speed
WSMR	White Sands Missile Range
WD	Wind Direction

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Appendix A: Thompson Tower Data

This appendix is part of ARL-TR-2823, Surface Layer Stability Transition Research Maximum Time Delay from Sunrise/Non-Ideal Conditions: 2001 June Case Study, U.S. Army Research Laboratory, White Sands Missile Range, NM 88002-5501.

A Eulerian (fixed point) perspective on the atmospheric conditions during the Nighttime (Stable) to Daytime (Unstable) transition was quantitatively recorded by the Thompson Tower time-series data. Thermodynamic data sampling was executed at 2 m and 38 m above ground level (AGL). Wind data was acquired at 5 m and 39 m AGL. For convenience, the data representing the lower layer is designated with a brown box and the upper layer with a blue open circle. Efficiency has dictated that all three Sub-cases (Stable, Neutral, Unstable) be presented in a single time-series plot. Approximate times for each Sub-case were:

Stable	0500–0600 MDT
Neutral	0630–0730 MDT
Unstable	0800–0830 MDT

The 2001 June 19 Pre-Test data were included for completeness. The following are the four sections of Appendix A:

- Figures A1–A7: 2001 June 19
- Figures A8–A14: 2001 June 20
- Figures A15–A21: 2001 June 21
- Figures A22–A28: 2001 June 22

Figures A1–A7: 2001 June 19-Thompson Tower Data

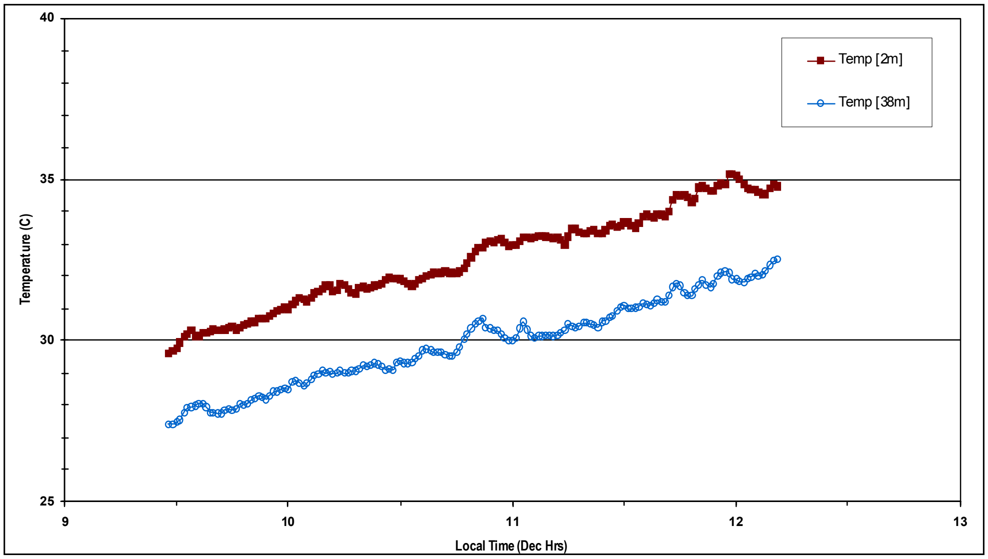

Figure A1. Thompson Tower-2001 June 19: Temperature.

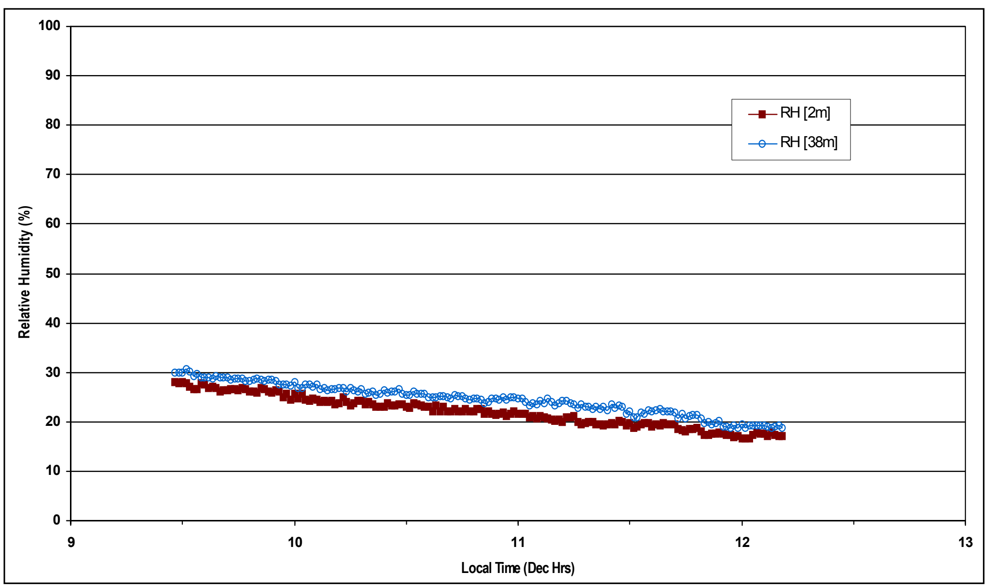

Figure A2. Thompson Tower-2001 June 19: Relative Humidity.

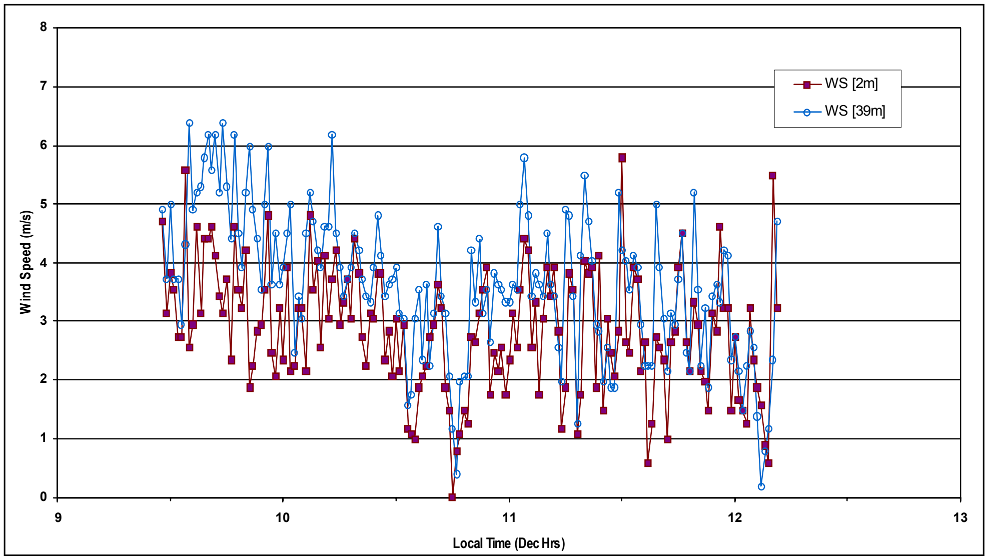

Figure A3. Thompson Tower-2001 June 19: Wind Speed.

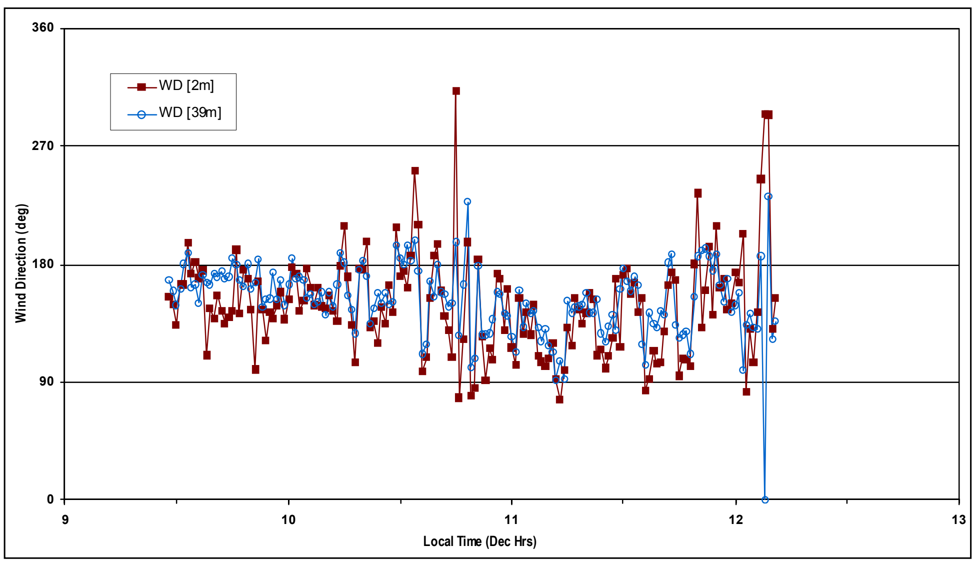

Figure A4. Thompson Tower-2001 June 19: Wind Direction.

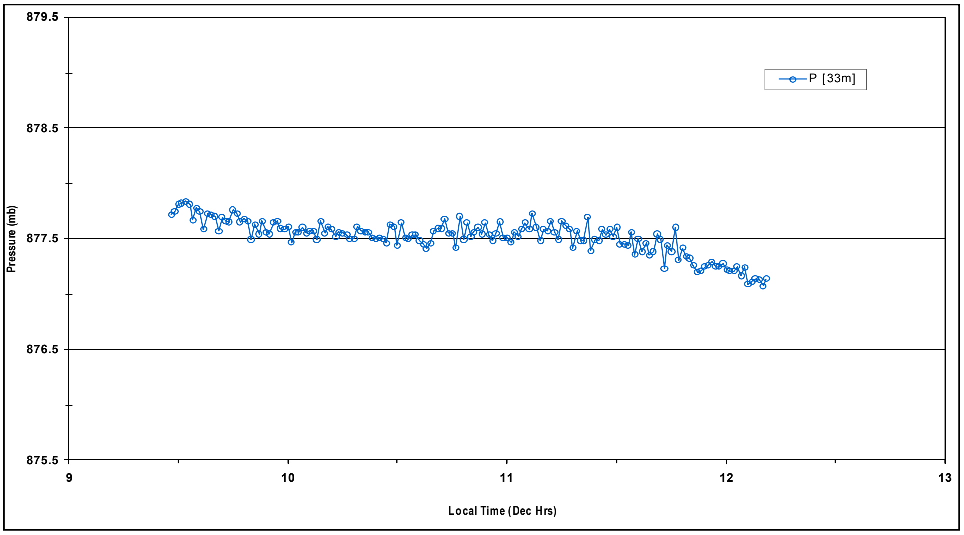

Figure A5. Thompson Tower-2001 June 19: Pressure.

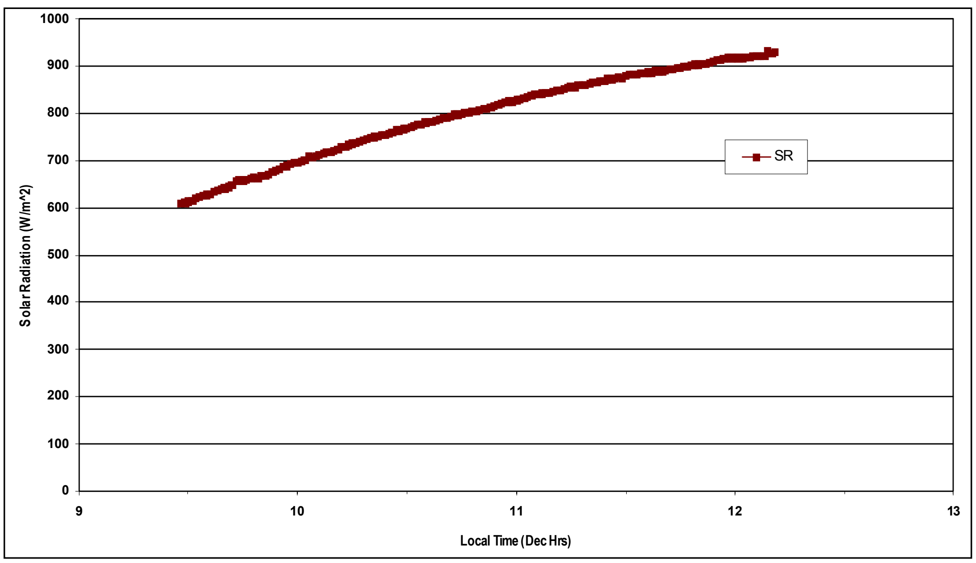

Figure A6. Thompson Tower-2001 June 19: Solar Radiation.

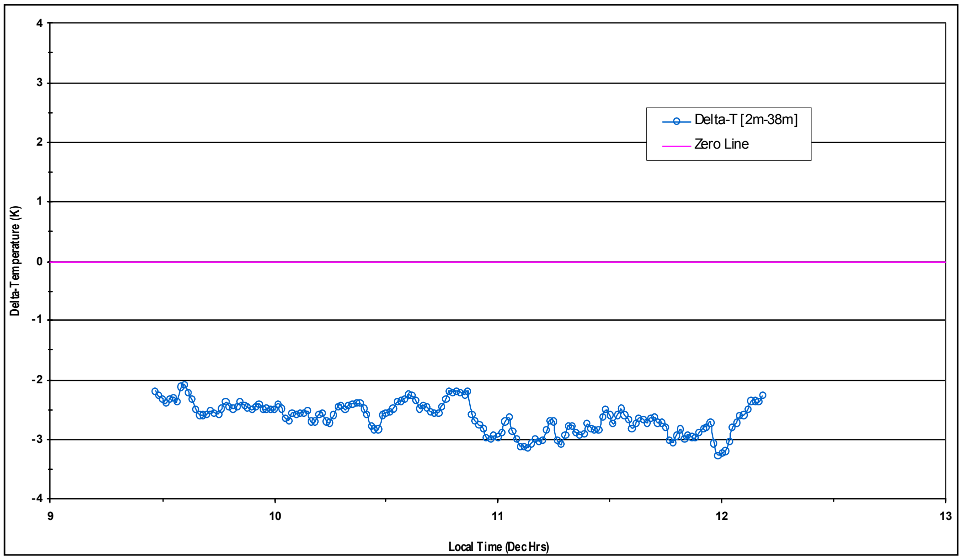

Figure A7. Thompson Tower-2001 June 19: Delta-T.

Figures A8–A14: 2001 June 20-Thompson Tower Data

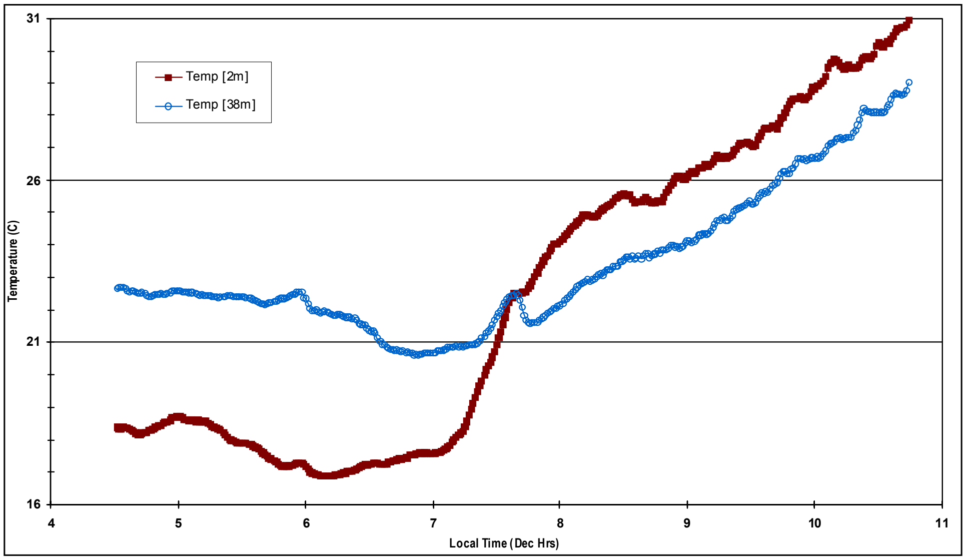

Figure A8. Thompson Tower-2001 June 20: Temperature.

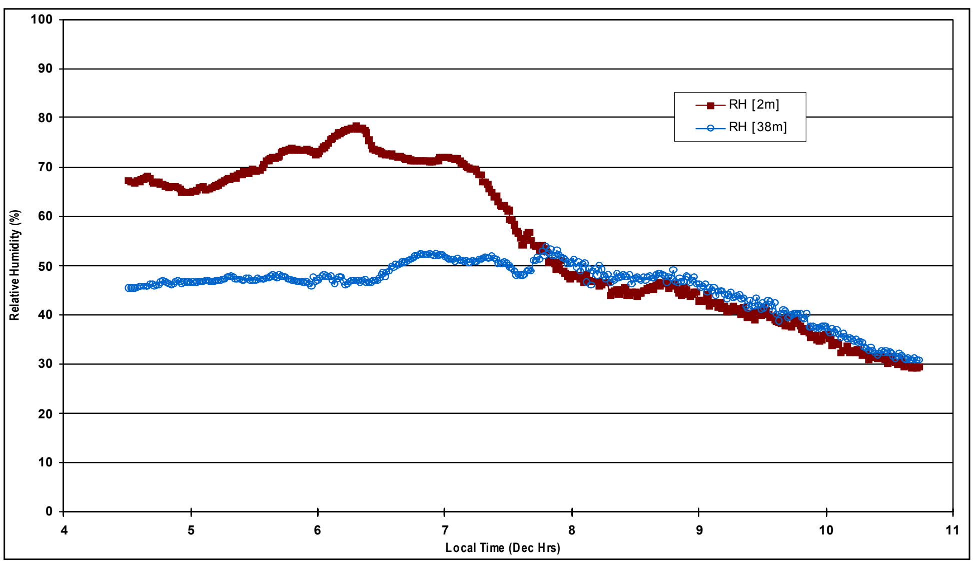

Figure A9. Thompson Tower-2001 June 20: Relative Humidity.

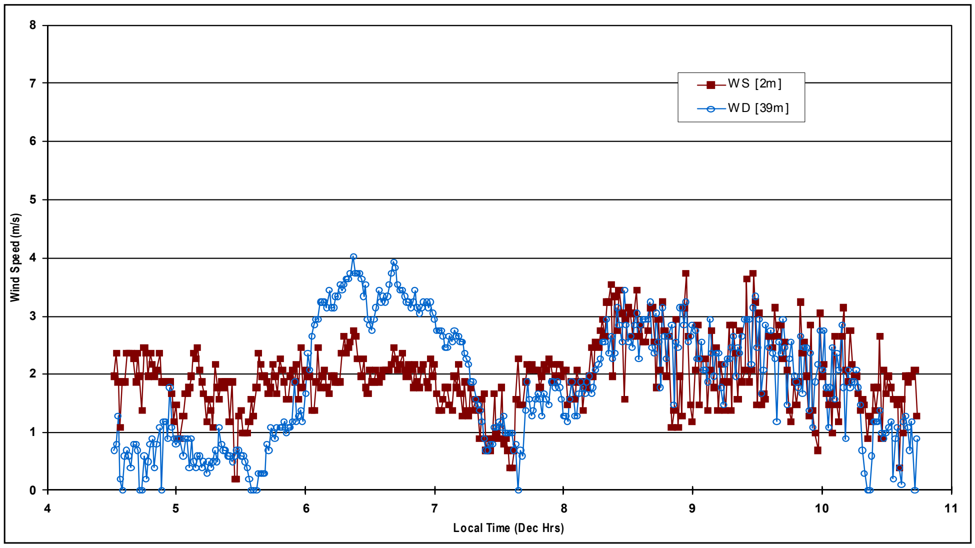

Figure A10. Thompson Tower-2001 June 20: Wind Speed.

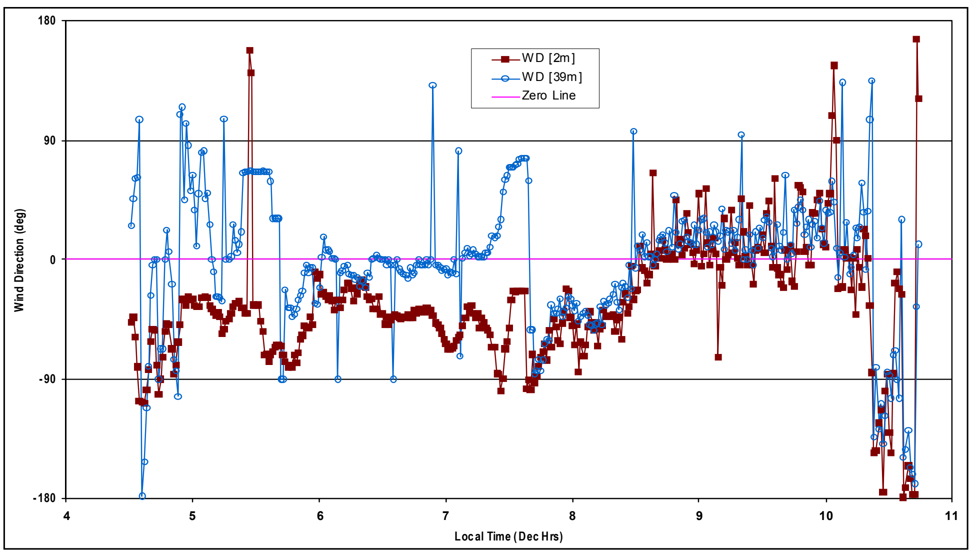

Figure A11. Thompson Tower-2001 June 20: Wind Direction.

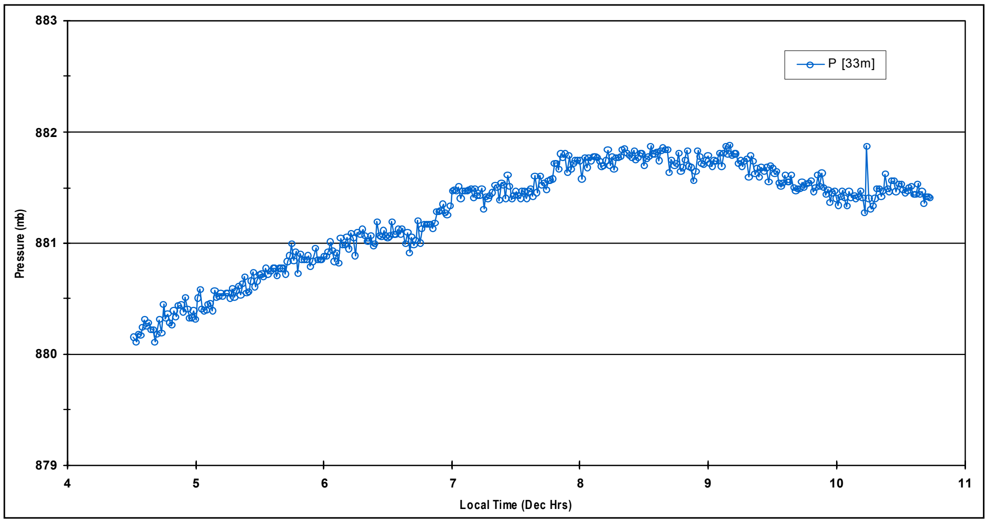

Figure A12. Thompson Tower-2001 June 20: Pressure.

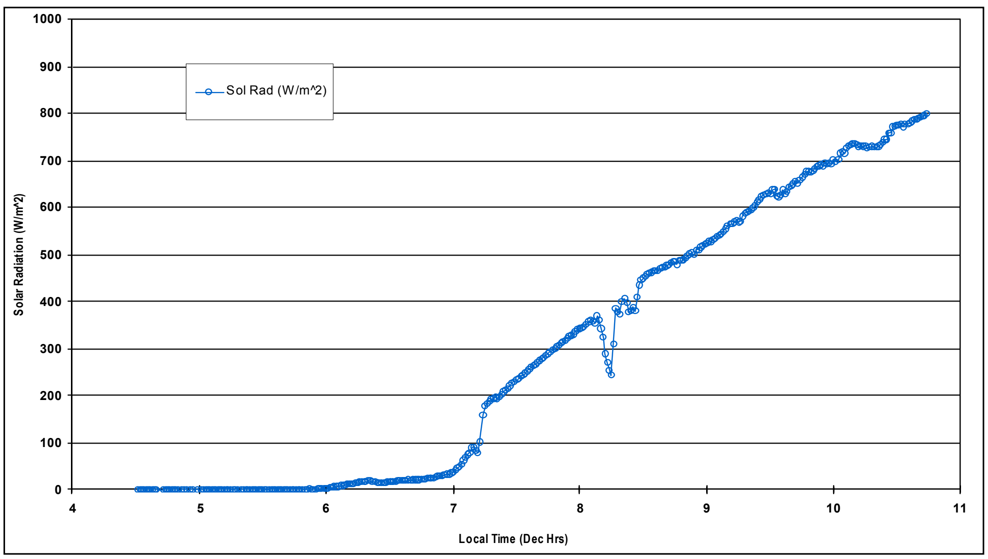

Figure A13. Thompson Tower-2001 June 20: Solar Radiation.

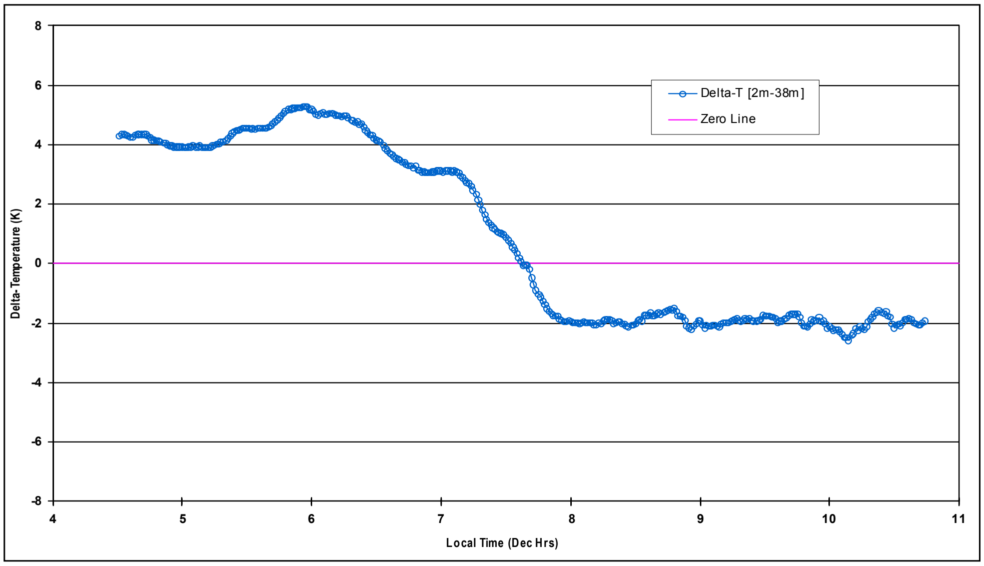

Figure A14. Thompson Tower-2001 June 20: Delta-T.

Figures A15–A21: 2001 June 21-Thompson Tower Data

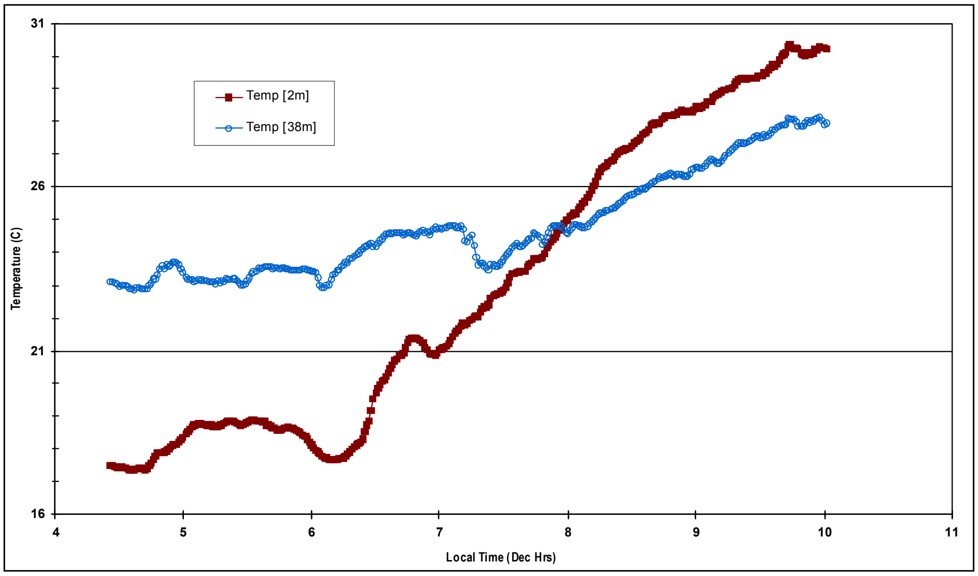

Figure A15. Thompson Tower-2001 June 21: Temperature.

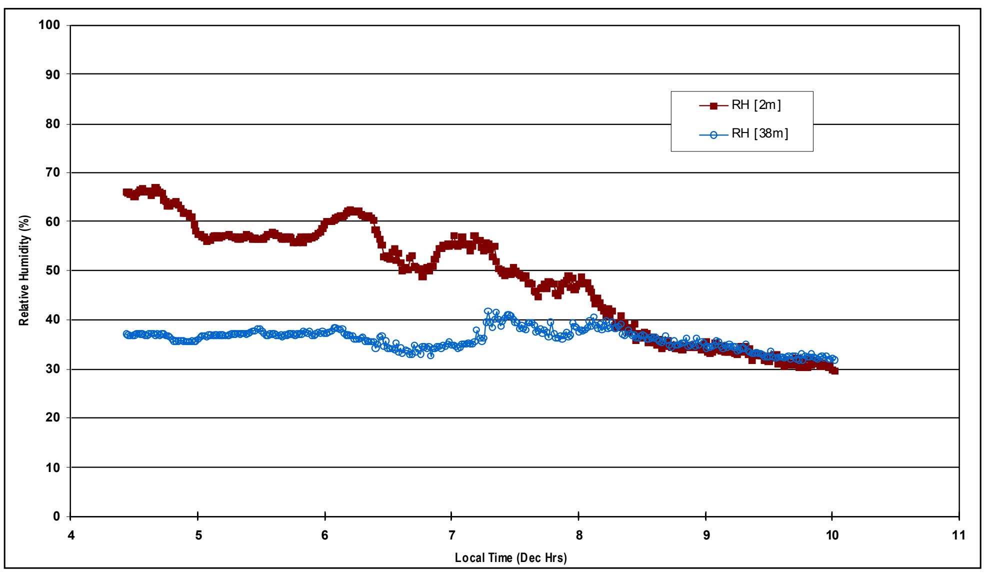

Figure A16. Thompson Tower-2001 June 21: Relative Humidity.

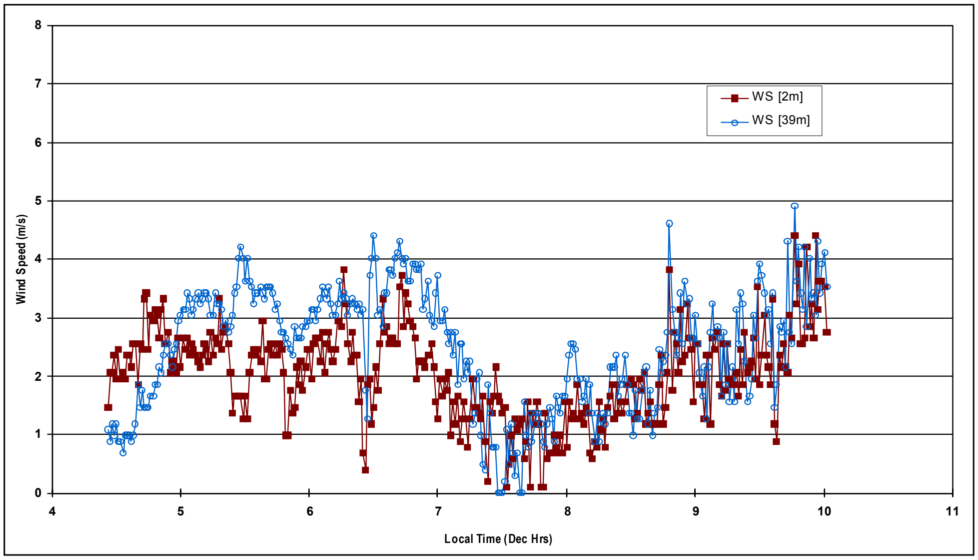

Figure A17. Thompson Tower-2001 June 21: Wind Speed.

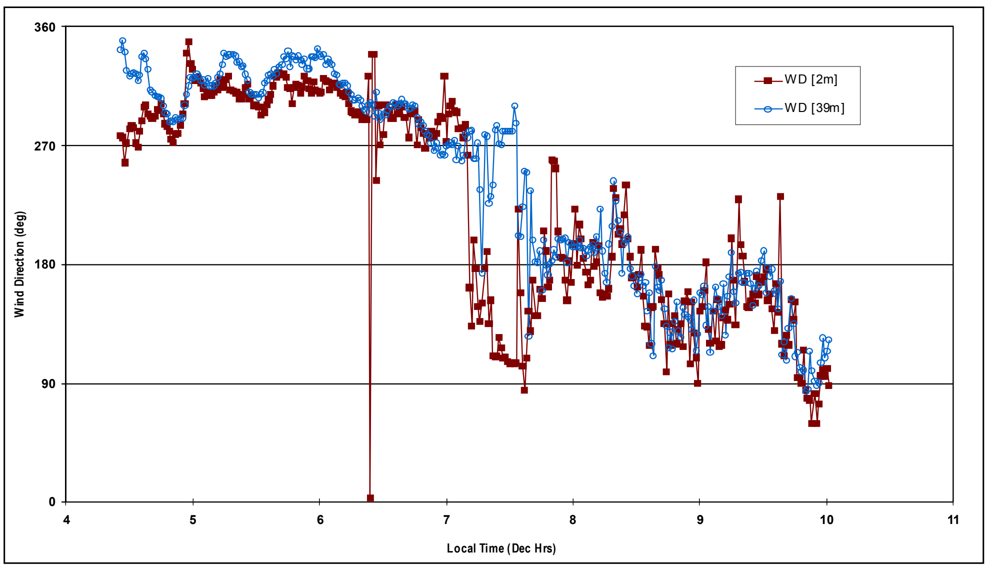

Figure A18. Thompson Tower-2001 June 21: Wind Direction.

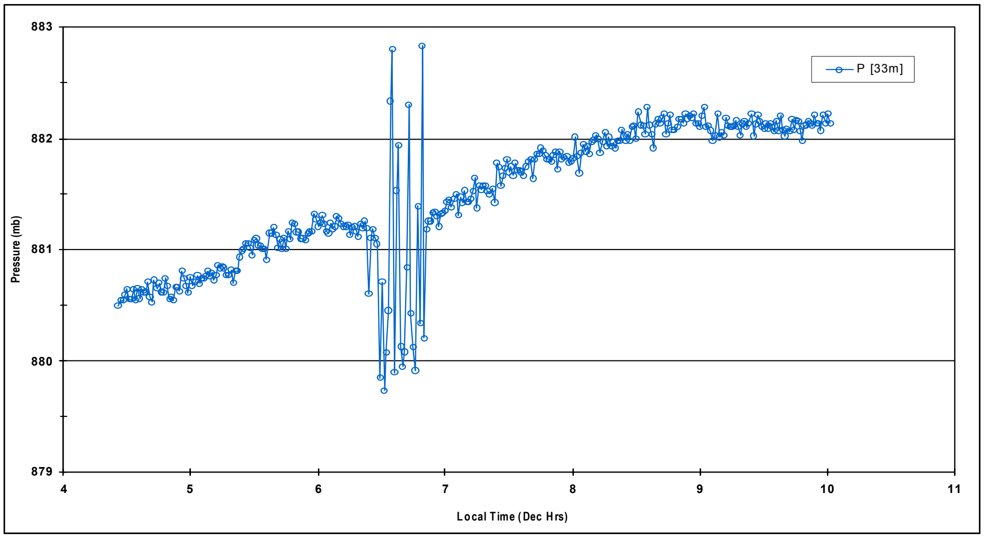

Figure A19. Thompson Tower-2001 June 21: Pressure.

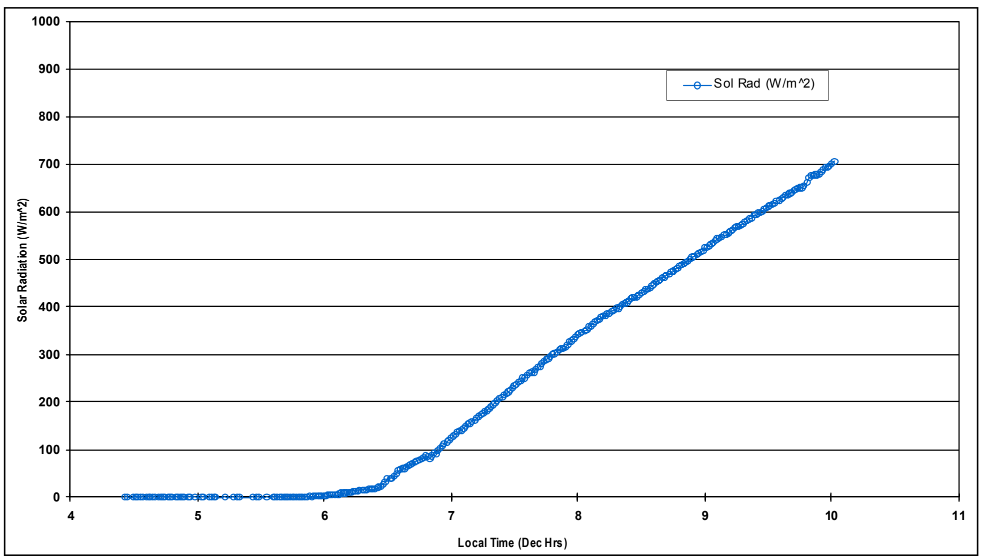

Figure A20. Thompson Tower-2001 June 21: Solar Radiation.

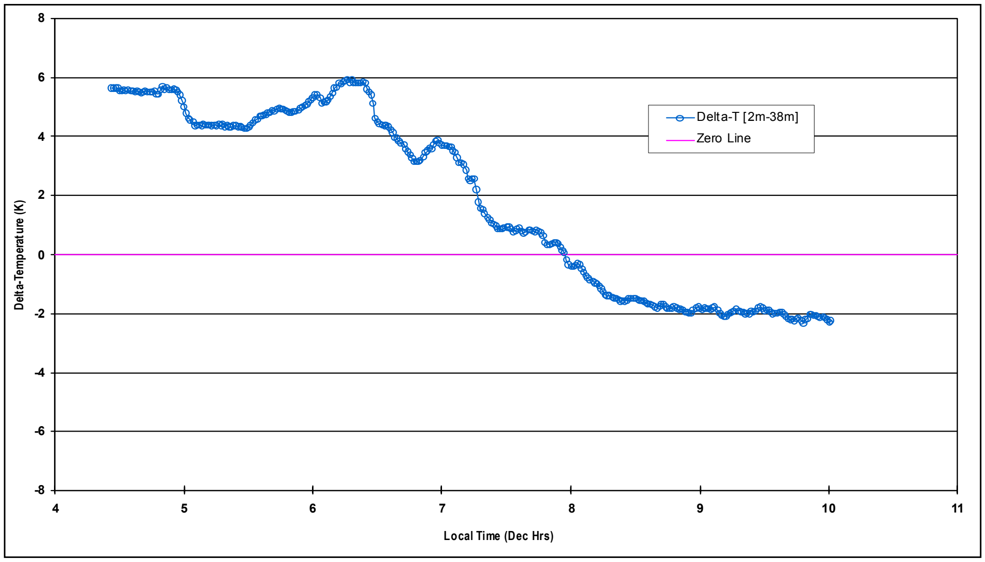

Figure A21. Thompson Tower-2001 June 21: Delta-T.

Figures A22–A28: 2001 June 22-Thompson Tower Data

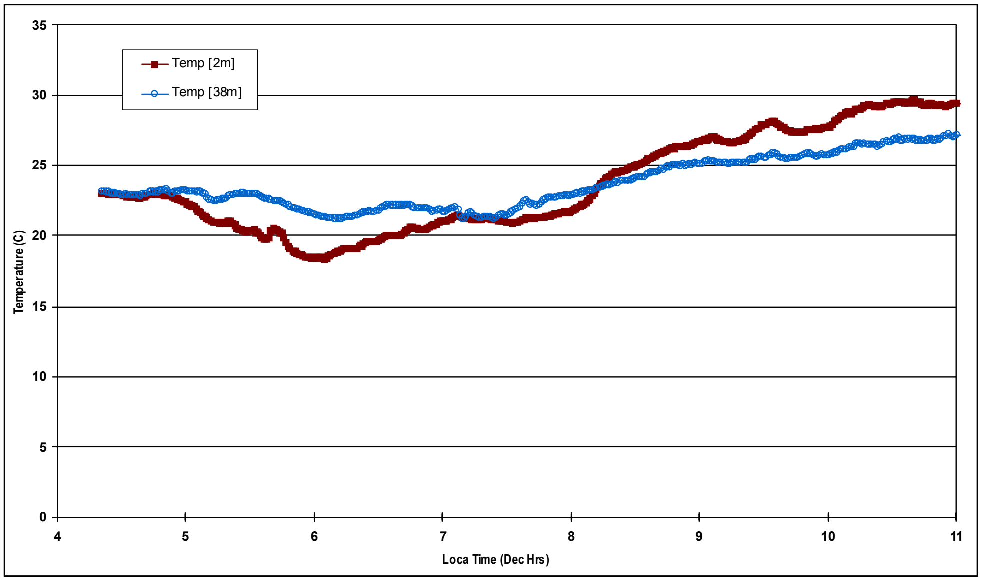

Figure A22. Thompson Tower-2001 June 22: Temperature.

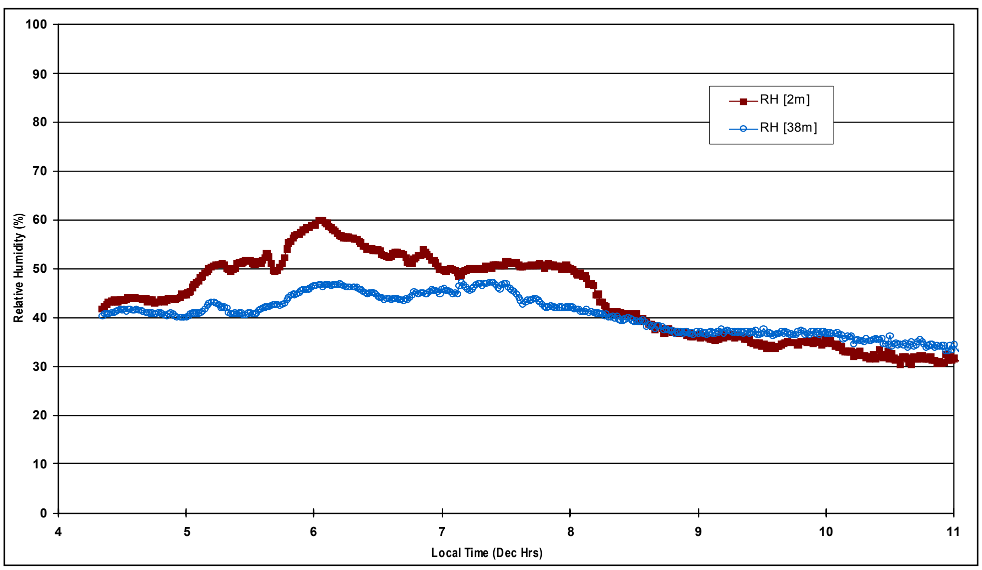

Figure A23. Thompson Tower-2001 June 22: Relative Humidity.

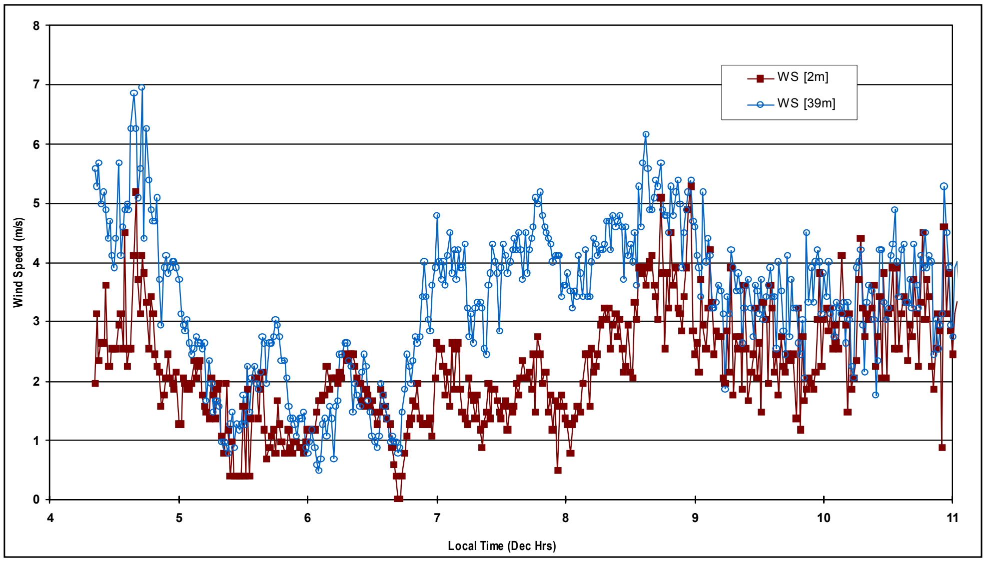

Figure A24. Thompson Tower-2001 June 22: Wind Speed.

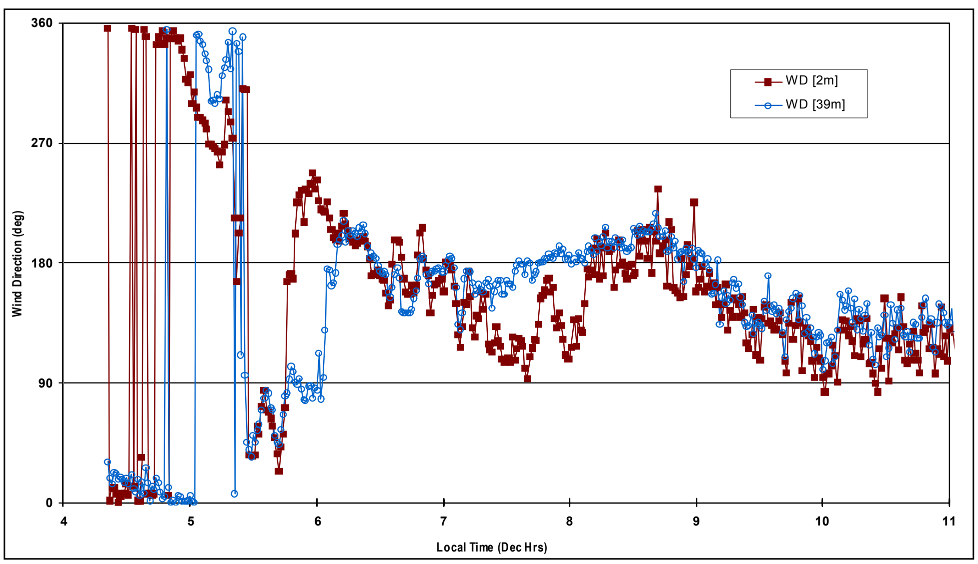

Figure A25. Thompson Tower-2001 June 22: Wind Direction.

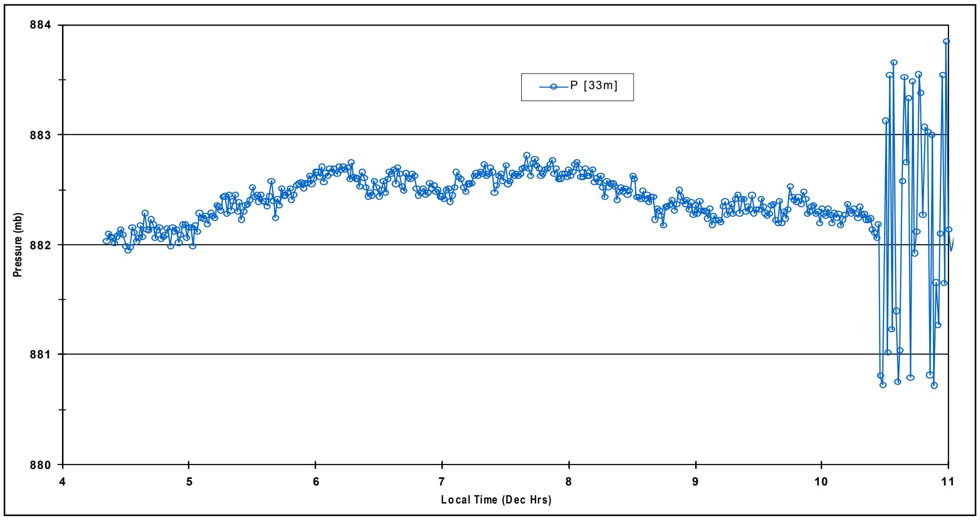

Figure A26. Thompson Tower-2001 June 22: Pressure.

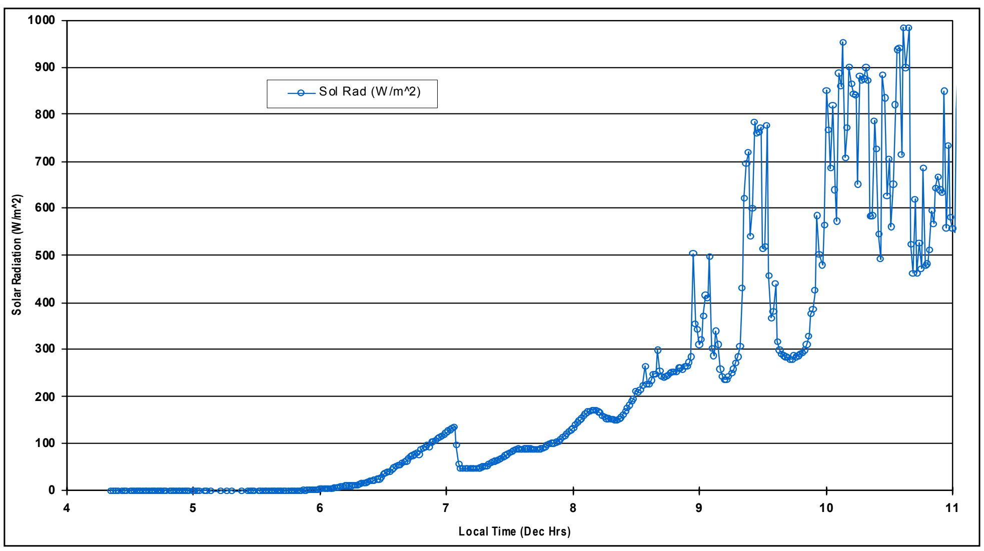

Figure A27. Thompson Tower-2001 June 22: Solar Radiation.

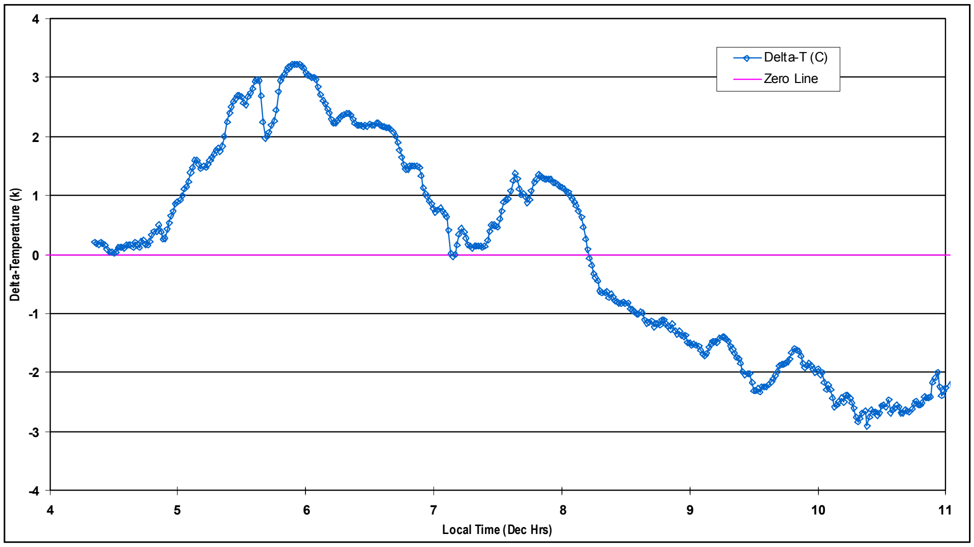

Figure A28. Thompson Tower-2001 June 22: Delta-T.

Appendix B: Rawinsonde Data

This appendix is part of ARL-TR-2823, Surface Layer Stability Transition Research Maximum Time Delay from Sunrise/Non-Ideal Conditions: 2001 June Case Study, U.S. Army Research Laboratory, White Sands Missile Range, NM 88002-5501.

A Lagrangian (following the parcel) perspective on the atmospheric conditions during the Nighttime (Stable) to Daytime (Unstable) transition was quantitatively recorded by the Thompson Site rawinsonde (RAOB) data. RAOB data referenced as 'C-station' were released at the White Sands Missile Range C-station launch site (within 5 miles of Thompson Tower). A full day's worth of data is presented on a single plot. The earliest Sub-case (Stable) is designated with a red solid box; an orange open circle shows the Neutral Sub-case; the Unstable Sub-case is a green solid triangle and any additional Unstable data is a blue open diamond. As a reminder, the general times designated for each Sub-case were:

Stable	0500–0600 MDT
Neutral	0630–0730 MDT
Unstable	0800–0830 MDT

The 1100 MDT, 2001 June 19 Pre-Test data were included for completeness. The following are the four sections of Appendix B:

- Figures B1–B6: 2001 June 19
- Figures B7–B12: 2001 June 20
- Figures B13–B18: 2001 June 21
- Figures B19–B24: 2001 June 22

Figures B1–B6: 2001 June 19-Rawinsonde Data

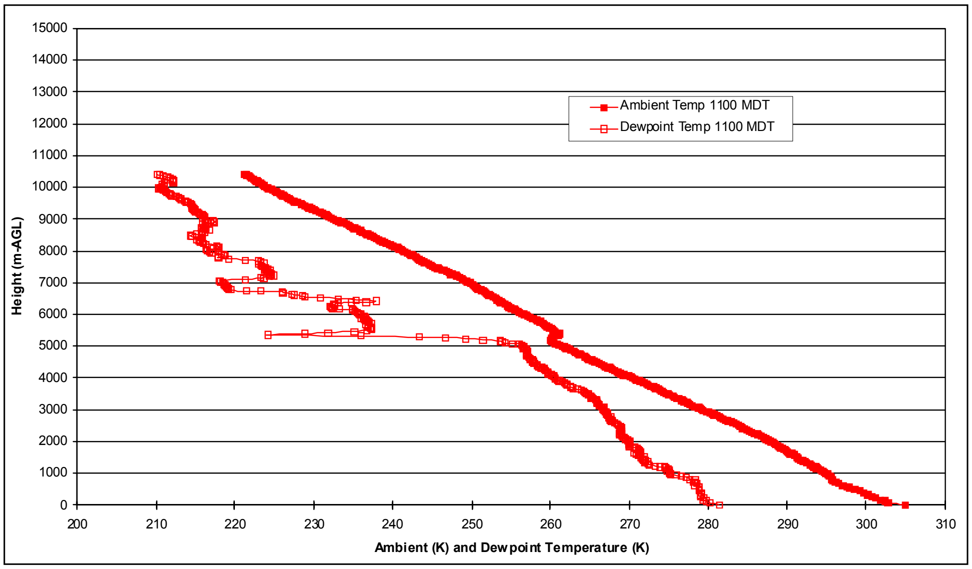

Figure B1. Thompson Tower RAOB Launch-2001 June 19: Temperature.

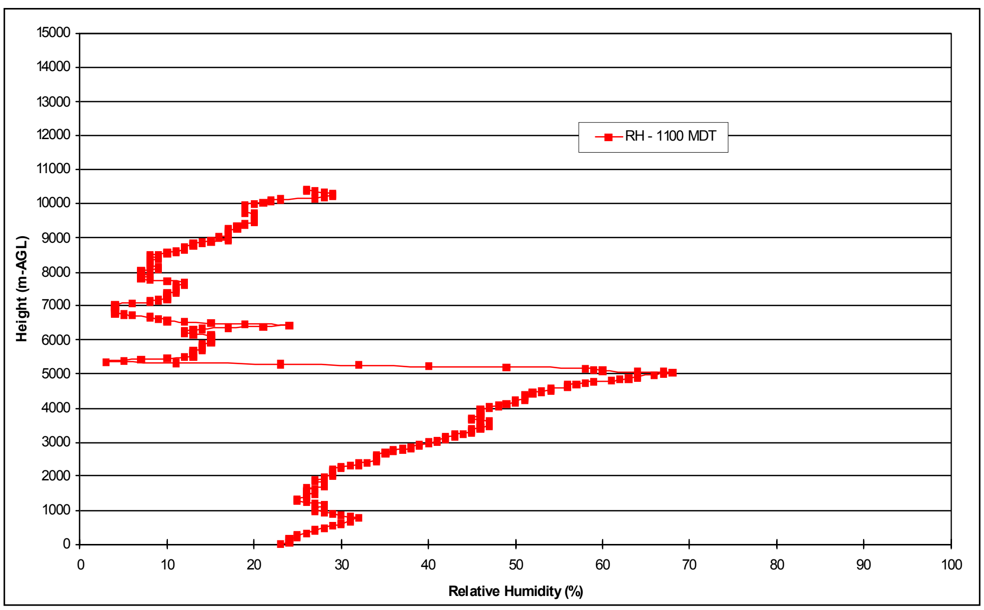

Figure B2. Thompson Tower RAOB Launch -2001 June 19: Relative Humidity.

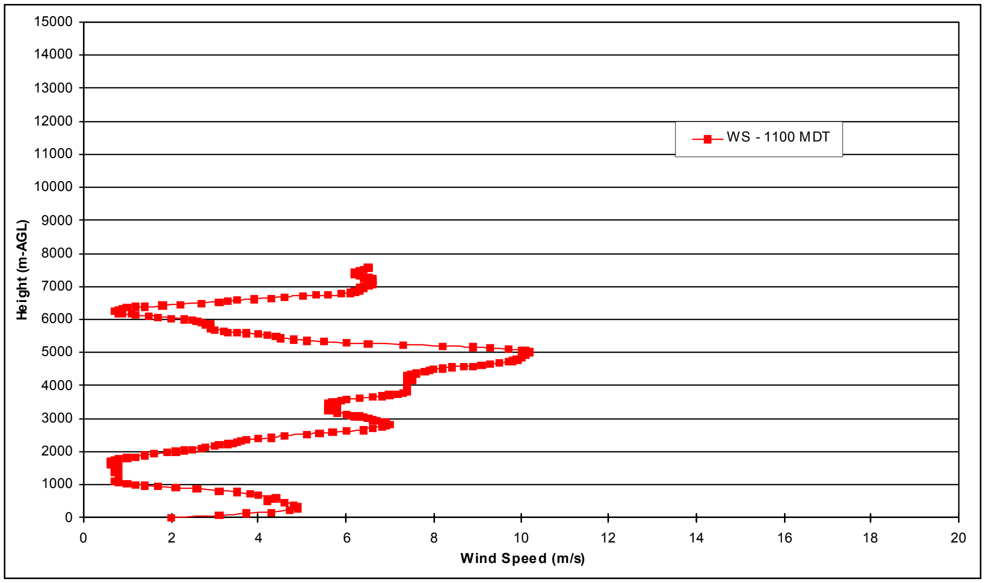

Figure B3. Thompson Tower RAOB Launch-2001 June 19: Wind Speed.

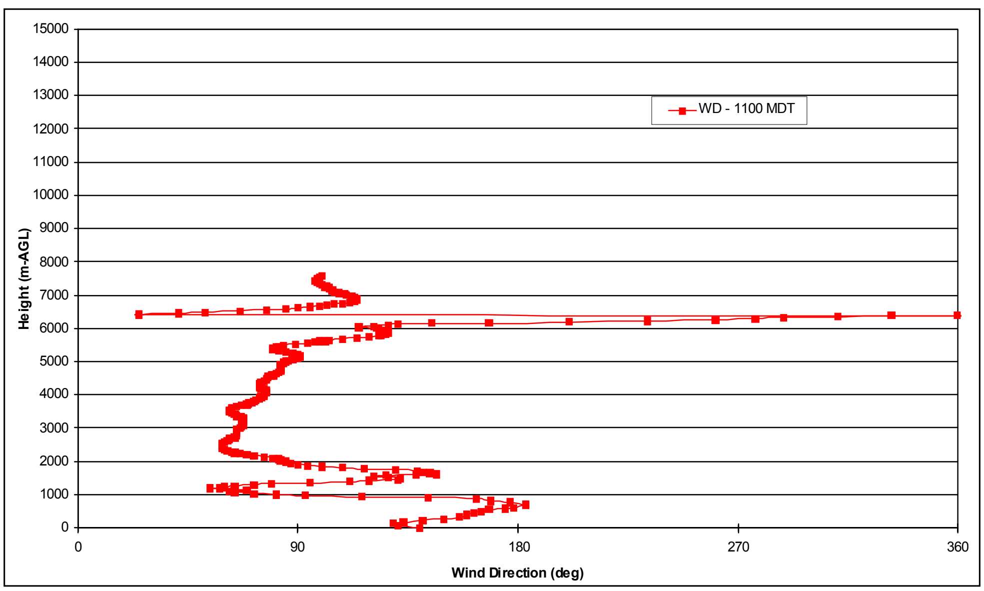

Figure B4. Thompson Tower RAOB Launch-2001 June 19: Wind Direction.

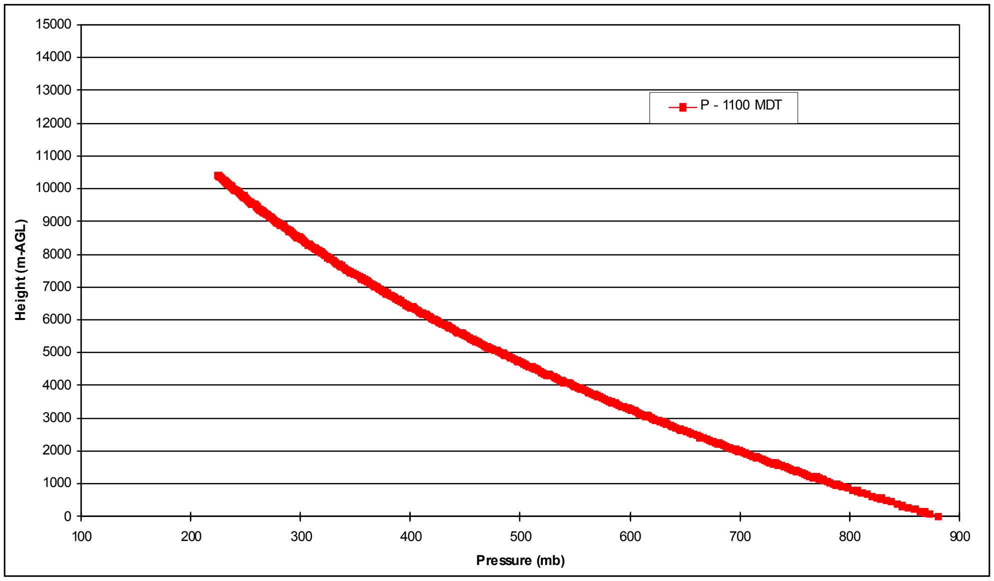

Figure B5. Thompson Tower RAOB Launch-2001 June 19: Pressure.

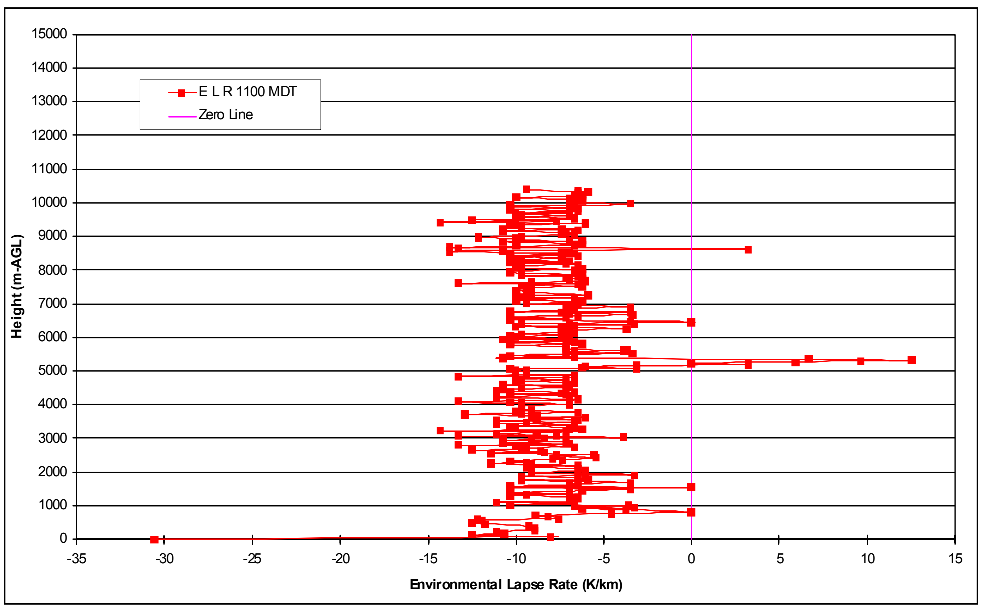

Figure B6. Thompson Tower RAOB Launch-2001 June 19: ELR.

Figures B7–B12: 2001 June 20-Rawinsonde Data

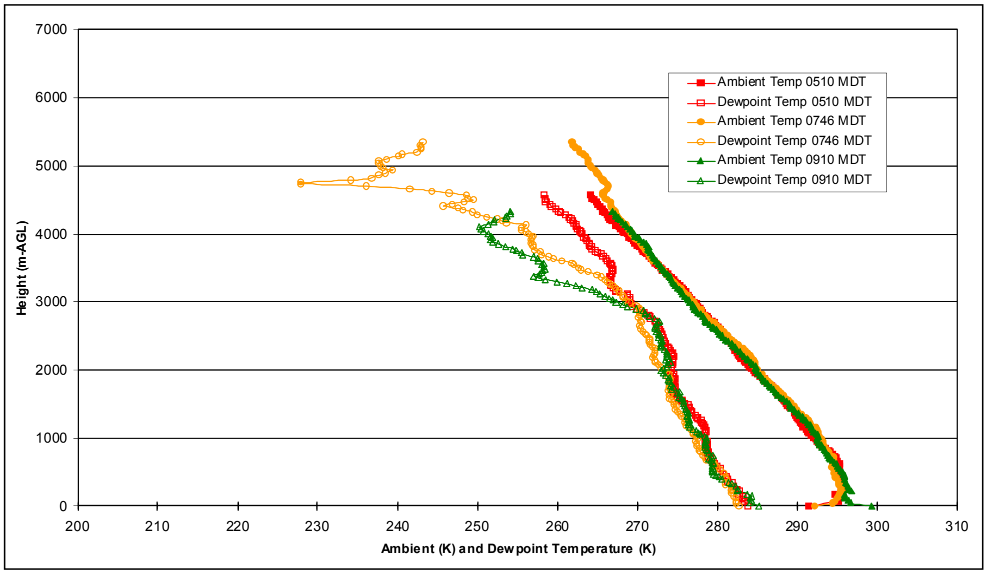

Figure B7. Thompson Tower RAOB Launch-2001 June 20: Temperature.

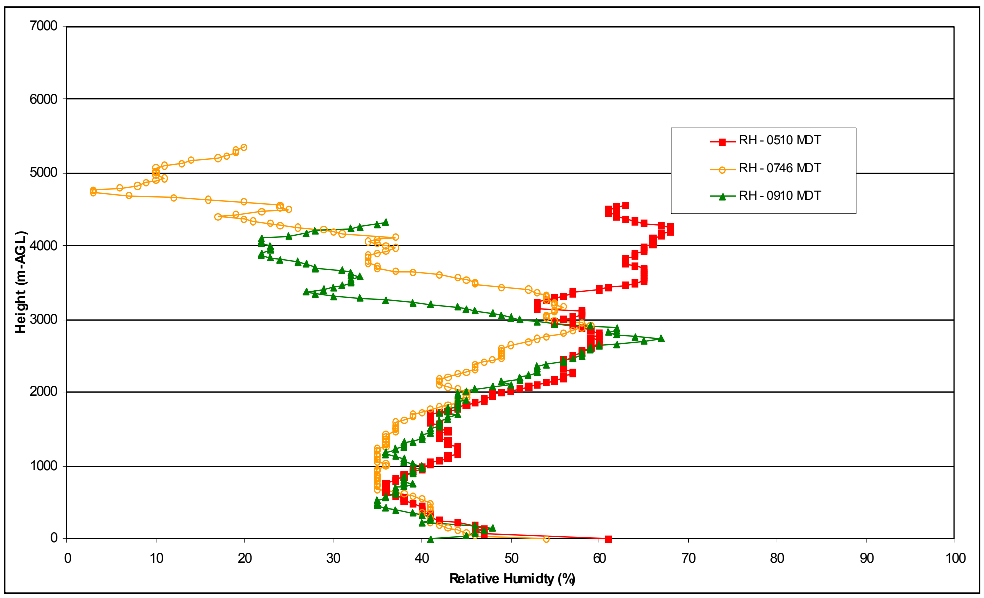

Figure B8. Thompson Tower RAOB Launch-2001 June 20: Relative Humidity.

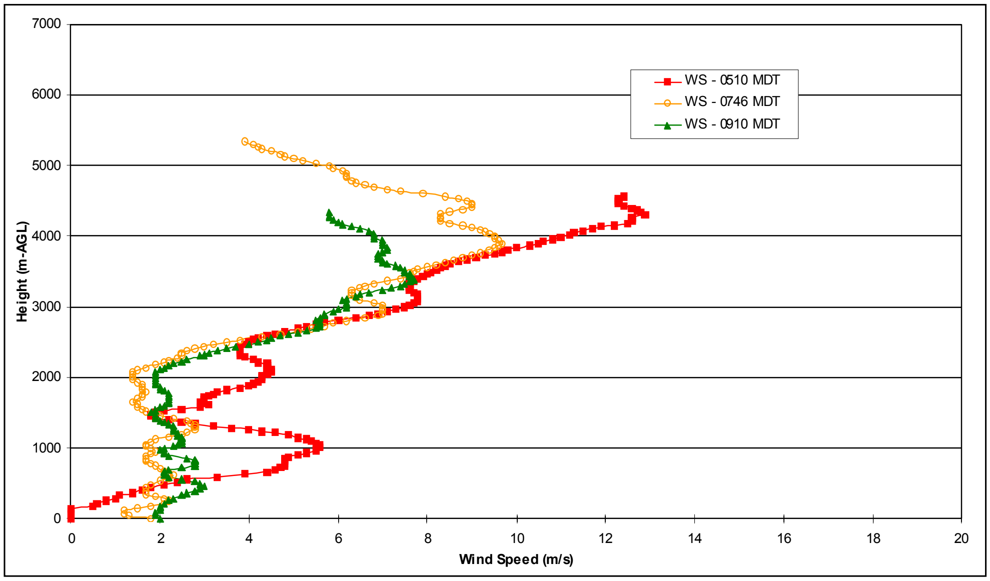

Figure B9. Thompson Tower RAOB Launch-2001 June 20: Wind Speed.

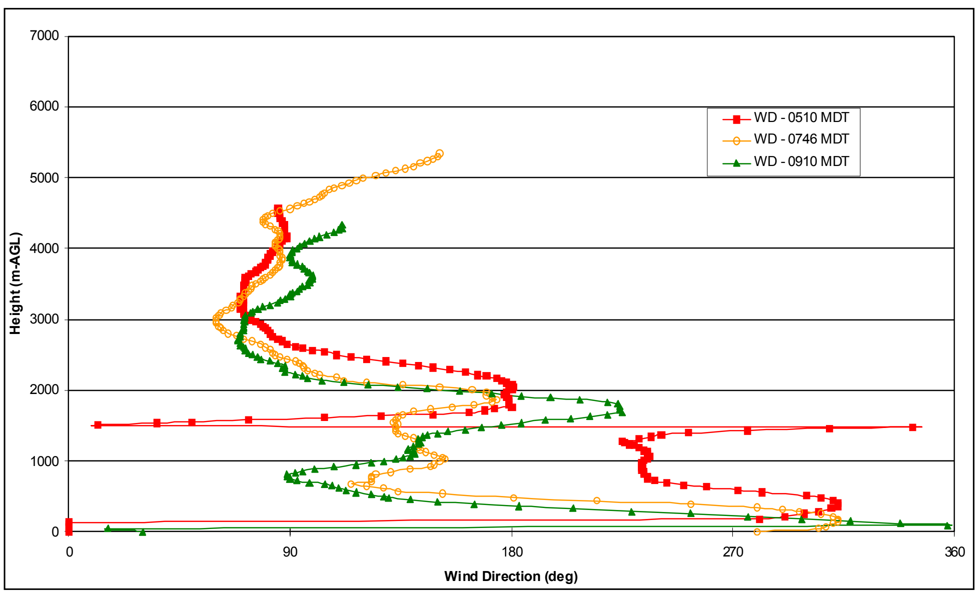

Figure B10. Thompson Tower RAOB Launch-2001 June 20: Wind Direction.

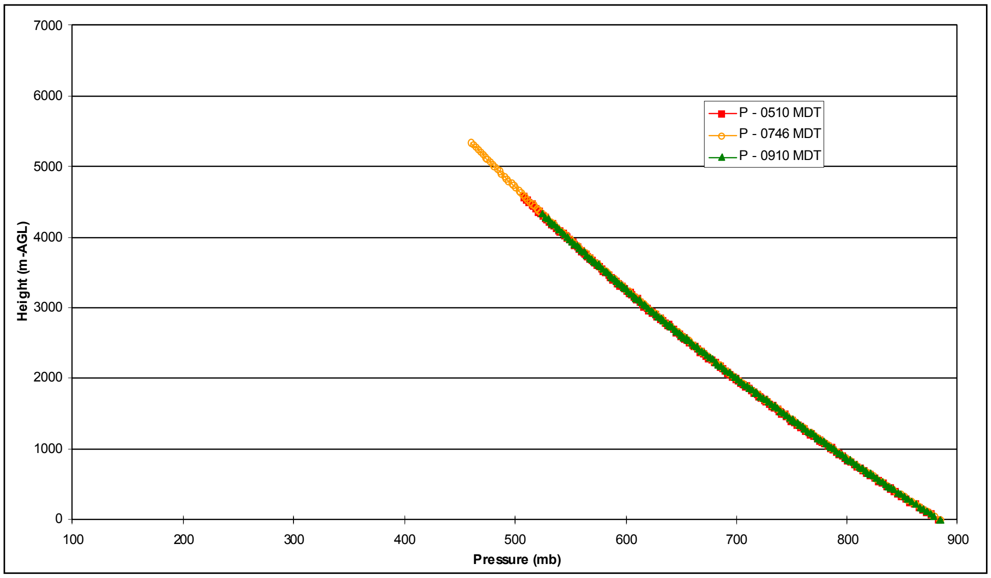

Figure B11. Thompson Tower RAOB Launch-2001 June 20: Pressure.

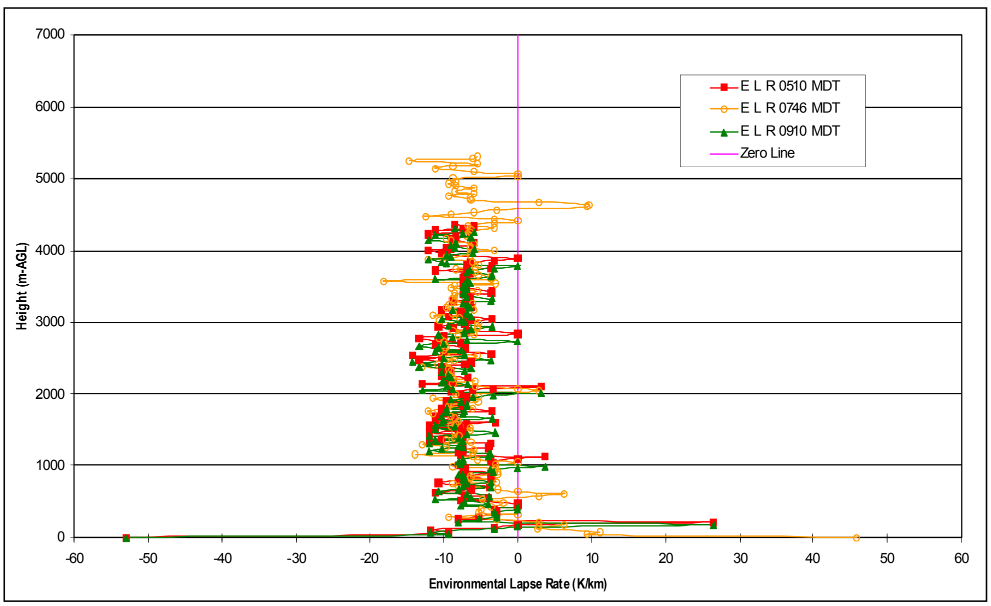

Figure B12. Thompson Tower-2001 June 20: ELR.

Figures B13–B18: 2001 June 21-Rawinsonde Data

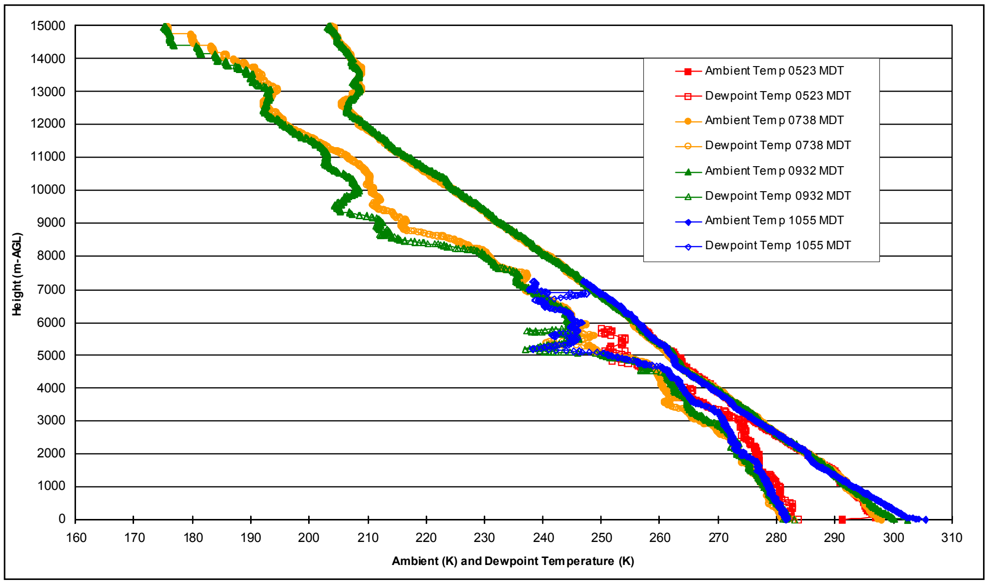

Figure B13. Thompson Tower RAOB Launch-2001 June 21: Temperature.

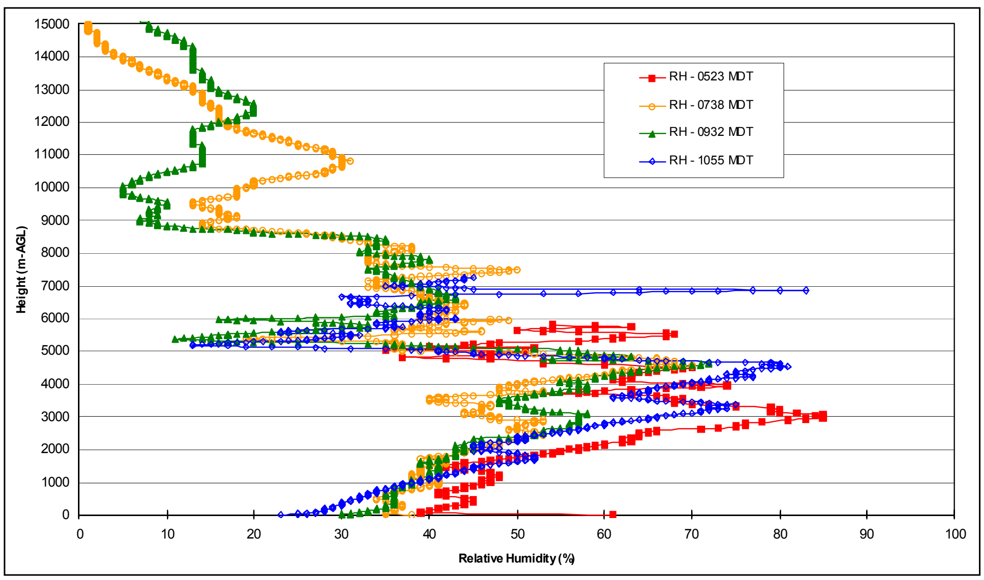

Figure B14. Thompson Tower RAOB Launch-2001 June 21: Relative Humidity.

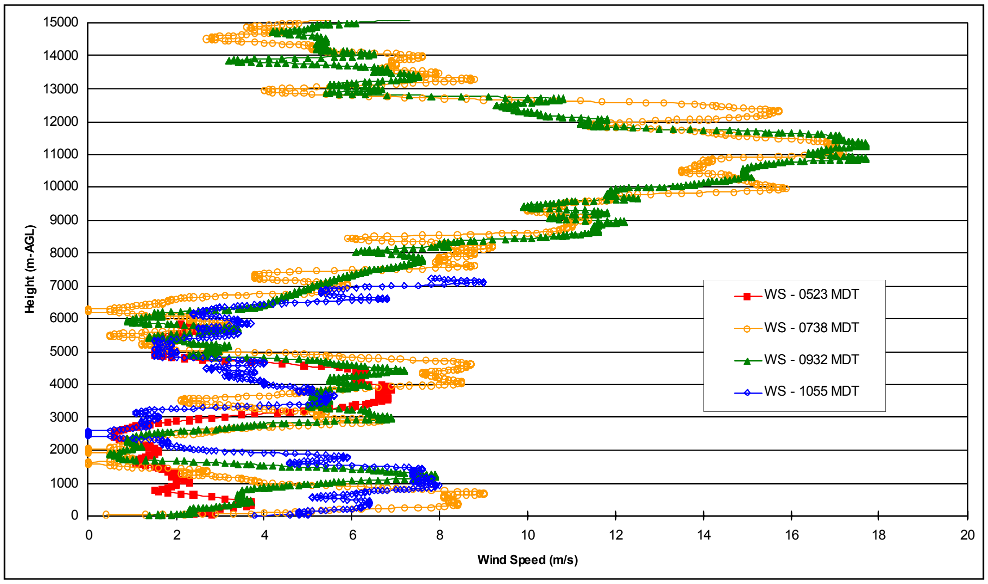

Figure B15. Thompson Tower RAOB Launch-2001 June 21: Wind Speed.

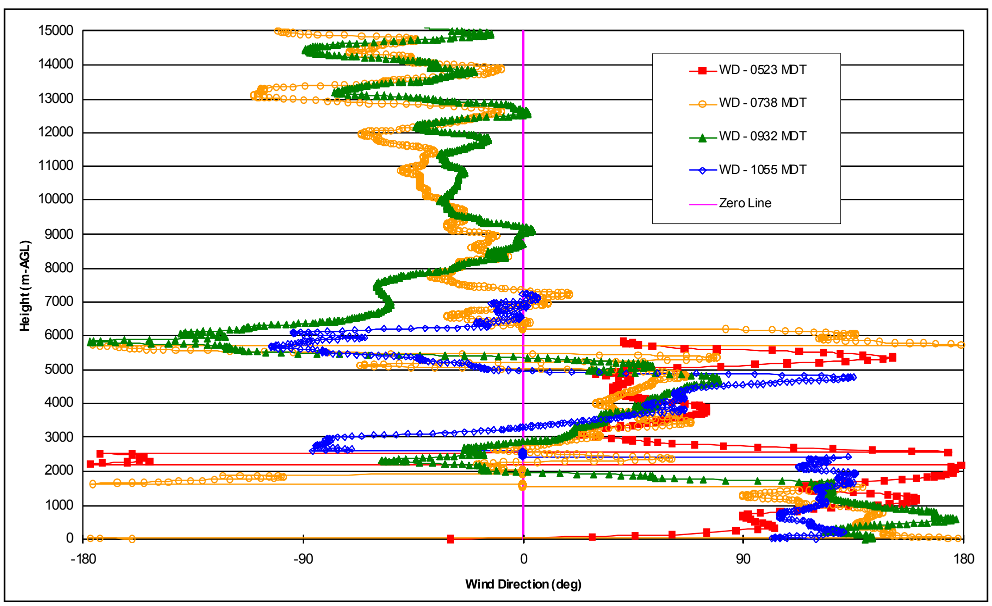

Figure B16. Thompson Tower RAOB Launch-2001 June 21: Wind Direction.

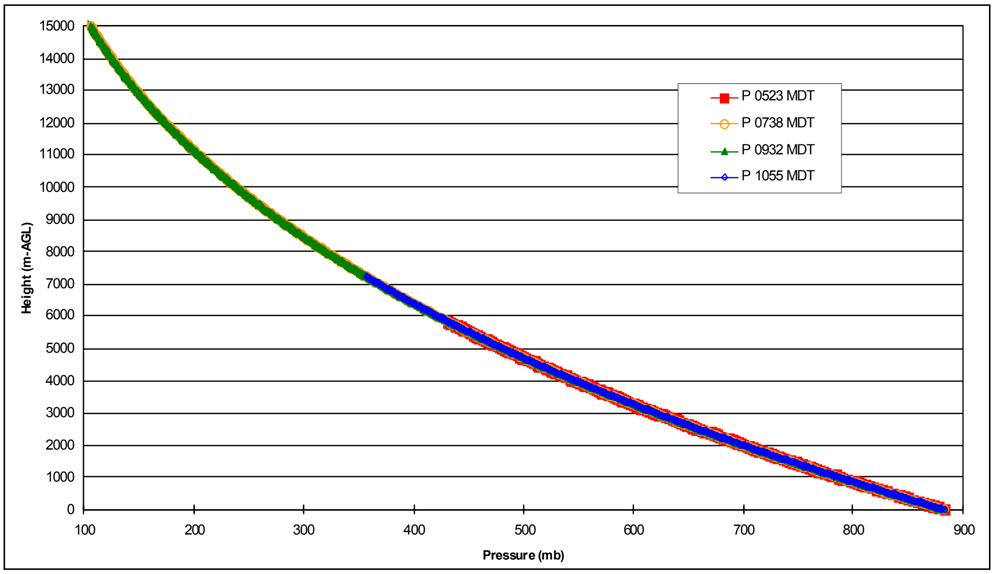

Figure B17. Thompson Tower RAOB Launch-2001 June 21: Pressure.

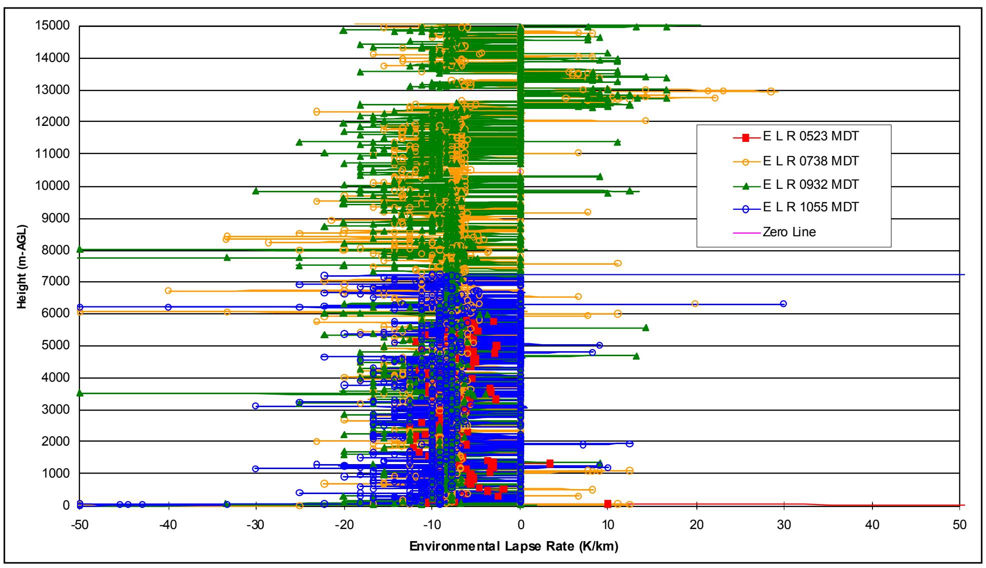

Figure B18. Thompson Tower RAOB Launch-2001 June 21: ELR.

Figures B19–B24: 2001 June 22-Rawinsonde Data

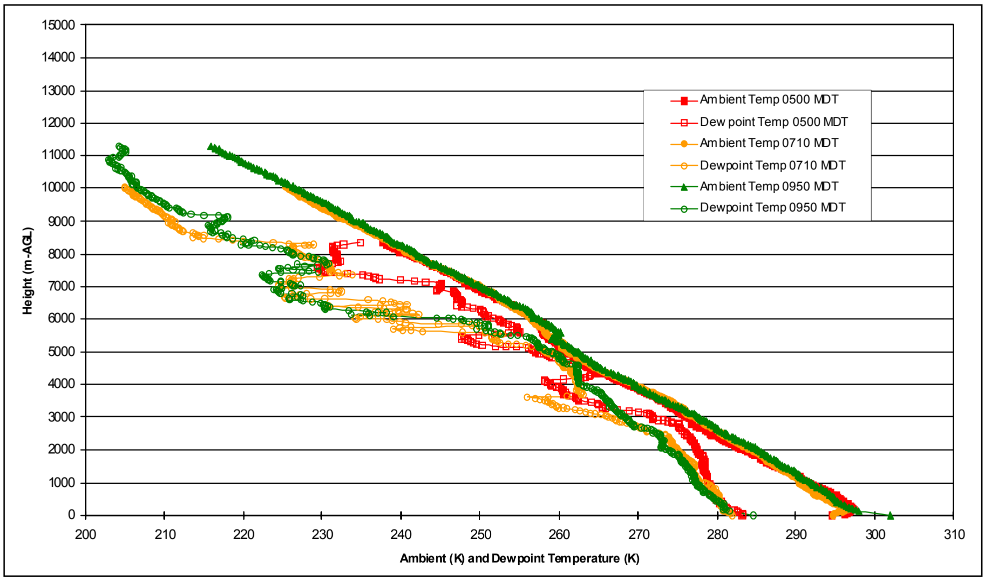

Figure B19. Thompson Tower RAOB Launch-2001 June 22: Temperature.

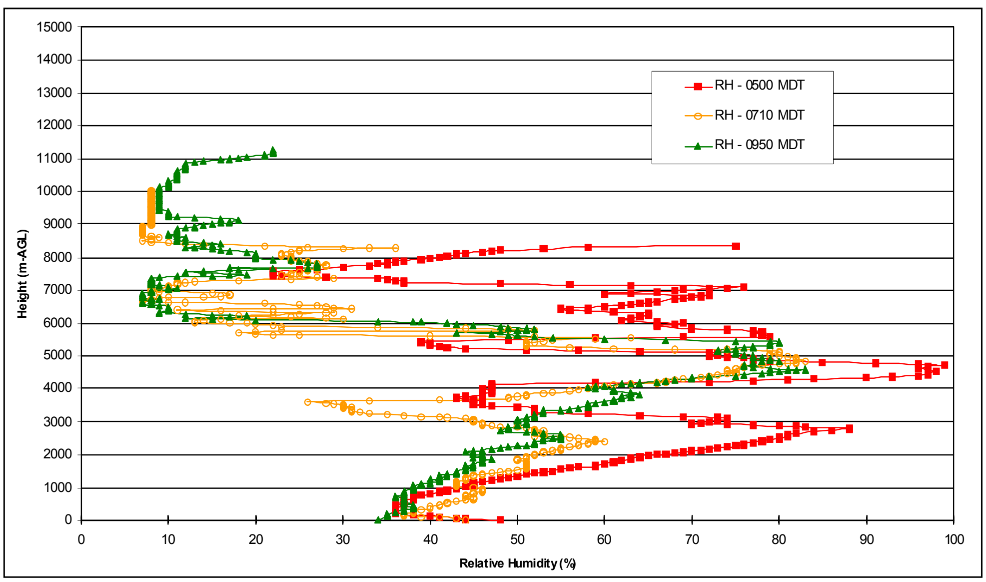

Figure B20. Thompson Tower RAOB Launch-2001 June 22: Relative Humidity.

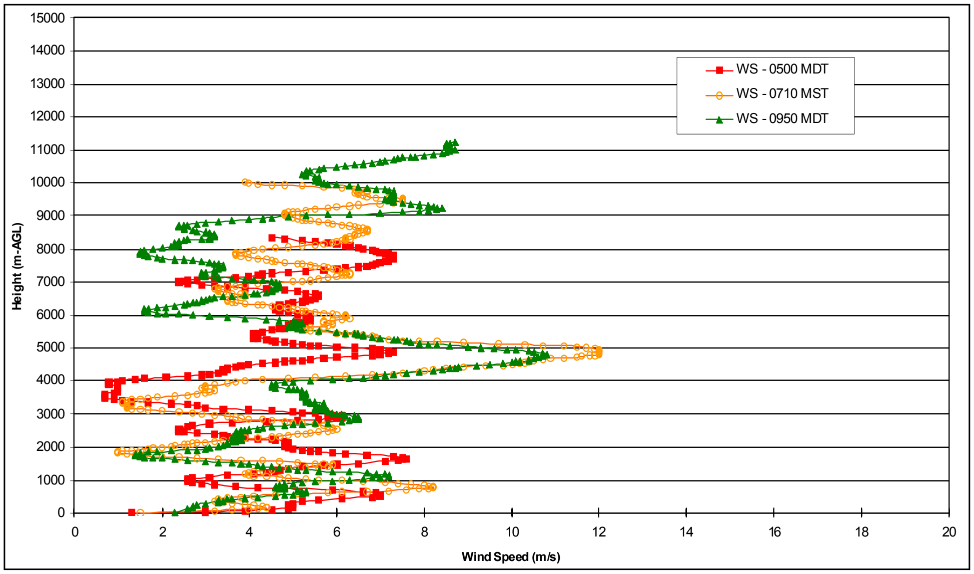

Figure B21. Thompson Tower RAOB Launch-2001 June 22: Wind Speed.

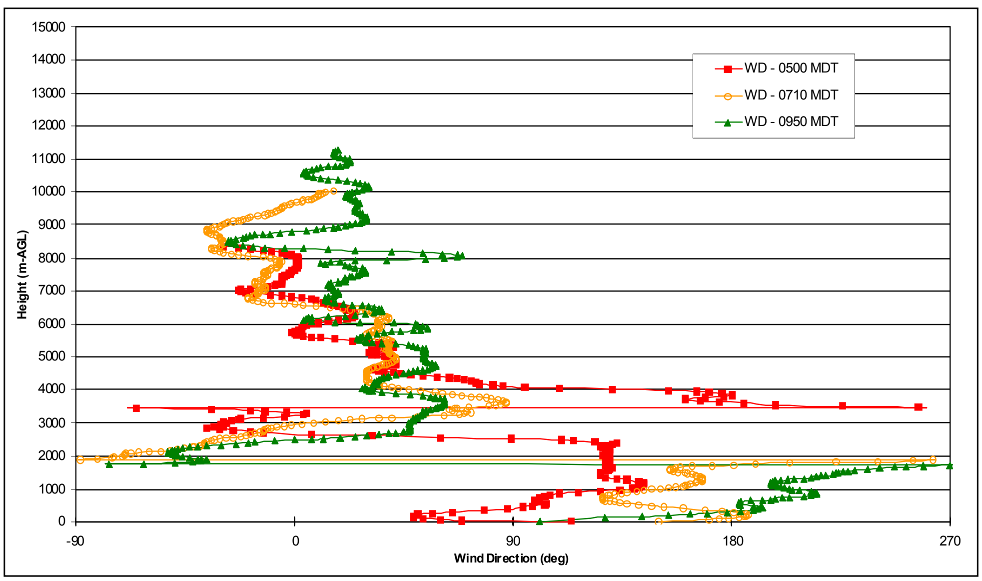

Figure B22. Thompson Tower RAOB Launch-2001 June 22: Wind Direction.

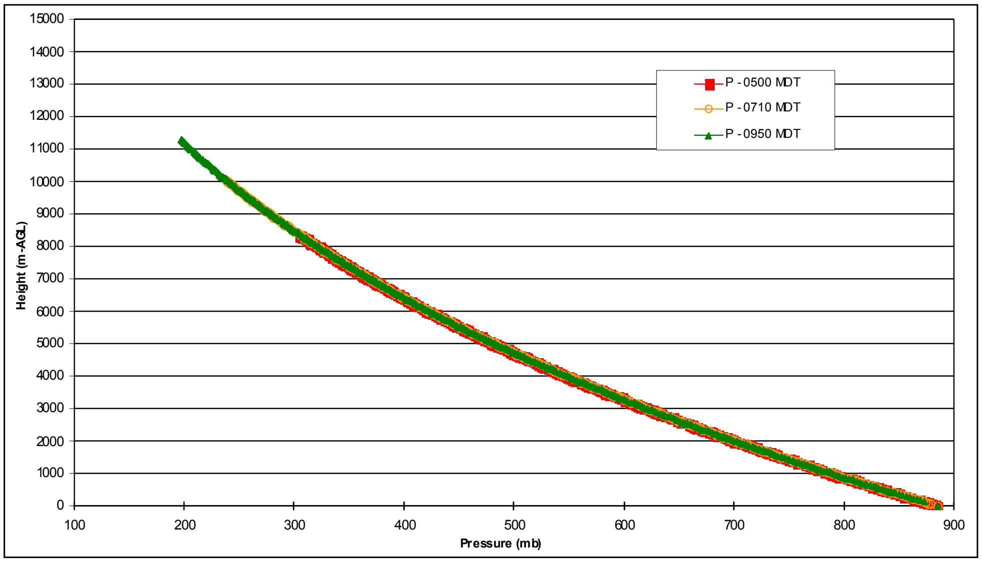

Figure B23. Thompson Tower RAOB Launch-2001 June 22: Pressure.

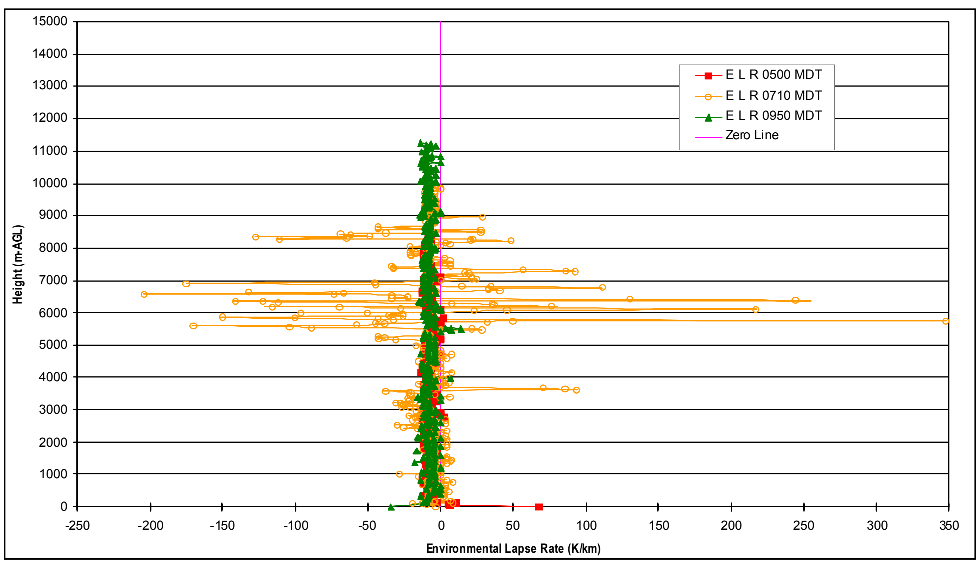

Figure B24. Thompson Tower RAOB Launch-2001 June 22: ELR.

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14. ABSTRACT

Near surface target acquisition and EO propagation significantly improve during the Surface Layer Stability Transition (SLST). Thus, this research expands Army Chief of Staff Shinseki's vision from "to see first" to, "to see better." The SLST is also the starting and ending points for the atmospheric convection growth phase, an important factor in chemical warfare modeling.

In 2001, the Meteorological-sensors Integration Team of the Army Research Laboratory conducted the second of three field tests with the primary purpose of characterizing, modeling and exploiting repeatable patterns in the lower portion of the atmospheric boundary layer. The repeatable patterns investigated were the morning Stability Transitions (ST) or Neutral Events (NE). The 2001 June 20–22 test dates were selected based on a forecasted maximum time interval between the local Sunrise and an Ideal case NE. Two other field tests addressed the minimum Sunrise-to-NE time interval (March and September). These Tests are documented separately.

The SLST Research pursued two measurement and analysis methods: Eulerian (Tower data) and quasi-Lagrangian (Rawinsonde data). The June results were as unexpected as the atypical Monsoon weather conditions observed. Excellent examples of Extended and Multiple STs were quantified by the data. A ST lasting at least 26 minutes surprised scientists by occurring well before sunrise and the morning twilight. The cumulative findings over this 2001 Solstice time period have expanded the documented character of a desert stable-neutral-unstable morning transition. The information in this report is a useful building block in support of the primary goal.

15. SUBJECT TERMS

Stability Transition, Neutral Events, Non-Ideal Conditions, Boundary Layer, Extended and Multiple Neutral Events

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